MINING ENGINEERING.

A

PRACTICAL TREATISE

ON

COAL MINING.

BY

GEORGE G. ANDRÉ, F.G.S.,

ASSOC. INST. C.E.; MINING CIVIL ENGINEER; MEMBER OF THE SOCIETY OF ENGINEERS.

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PREFACE.

Mining has at all times held an important position as a branch of Engineering, but at no time has that importance been so great or so manifest as at the present. The dependence of our material prosperity on an abundant supply of fuel, and the enormous and constantly increasing requirements of such prosperity have rendered the labour of the miner as essential to our existence as is that of the agriculturist, and created a demand that has given an amazing impetus to the progress of his calling. Scores of new pits are being sunk in every proved coal field, and new winnings are announced every day; and in fields yet untried, or only partially known, borings and sinkings are being pushed on with the utmost vigour. This state of things has created a demand for the knowledge of the Mining Engineer which the numbers of his profession are too few to supply; hence we find many men, whose training and practice have been in other branches of Engineering, abandoning their former duties in favour of those which offer a greater reward for their services. This is especially the case with young men fresh from their state of pupilage. Yet, notwithstanding this significant fact, and notwithstanding the position which this country holds as the chief producer of coal, the literature of Mining is singularly scant. It cannot be said that a complete treatise on Coal Mining exists in the English Language. There are, indeed, works on the subject, each excellent in its degree, but some are devoted to the description of merely local practice, while others are written in a style that is rather popular than suited to the requirements of the practical man. This is the more surprising, as both in France and in Germany the same defect has long since been made good. The consequence is, that neither he who turns his attention from other branches of Engineering to that of Mining, nor the pupil of the practising Mining Engineer, can find a work to which he may turn for instruction, and, in the case of the experienced man, to which he may refer in difficult cases for the practice of other districts. Moreover, the Legislature has now laid such responsibility upon the manager, that he, too, finds it necessary to possess a wider knowledge than was formerly found to be sufficient. To this class, a trustworthy book of reference, in cases of doubt and difficulty, must be of the greatest value.

To supply the want, which undoubtedly exists, is the task I have set myself to perform. Of the manner in which I have accomplished this task, it is not needful to speak; this much, however, it may be desirable to say, that nothing but what has been proved by experience, and is now in use, has received consideration; old and generally abandoned methods have been left in undisturbed possession of the realms of oblivion, and novelties introduced in their true character, as schemes whose merits have yet to be proved. Moreover, as the name of the latter is legion, only such have received notice as have already undergone the test of some genuine practice. Thus, practice, *present* practice, is the subject of this Treatise. And in describing this practice, I have not confined myself to personal experience, which would have rendered the Work a mere

vehicle of personal opinion, nor to the experience of a district, which would have limited its usefulness. Nor have I hesitated to introduce methods from French, Belgian, and German practice, when they have appeared to be applicable, either in their entirety or in a modified form, to the conditions which exist at home.

The Work is divided into Fifteen Chapters, as follows:

Each of these Chapters deals fully with the subject to the treatment of which it is devoted; and the value of the descriptions is materially increased by the addition of numerous drawings of a practical character.

The importance of geological knowledge to the Mining Engineer is so great and so obvious, that no apology would seem to be needed for prefacing a work on coal mining intended to be eminently practical, with a somewhat extended exposition of geological facts. Yet it may be urged, that the subject might be more conveniently studied in special treatises. My answer to this objection is twofold. First, no suitable treatise exists. Many and excellent works there are, it is true, but they have not been prepared with a special view to the requirements of the Mining Engineer. To obtain that knowledge which is necessary to enable him to discharge efficiently the duties of his profession, he is compelled to search through a mass of information, a large proportion of which, though eminently important and deeply interesting in itself, has only a remote bearing upon the practical operations of mining. I have therefore endeavoured to provide for this want, by supplying only so much of that information as he is in immediate need of. Secondly, the facts of geology are so closely and so inseparably bound up with the principles and practice of mining, that it is impossible to explain the principles and to describe the practice without making continual reference to those facts. Hence, by placing them in the position they now occupy, I have merely disentangled them from the text, thereby removing from the latter a source of interruption, and rendering the former more easy of reference.

GEO. G. ANDRÉ.

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MINING ENGINEERING.

CHAPTER I.

PRACTICAL GEOLOGY.

"THERE is no profession that comes so intimately in contact with geological phenomena, or that stands so much in need of a knowledge of geological truths, as that of the mining engineer. It is true that mining was practised, and in many instances successfully, long before geology had shaped itself into a science; but even the most successful practice was local and limited, and wanted that grasp of general truths which could enable it to pronounce on other districts, and deal successfully with their altered phenomena. The discrimination of the same formation in distant localities, the varying nature of sedimentary deposits, the relations of the eruptive to the stratified rocks, and the laws regulating the direction, character, and effects of faults, dykes, and veins—these, and many kindred problems, can be solved only by a pretty extensive acquaintance with the facts and principles of geology. It is true that much in successful mining depends on mechanical appliances, but the most skilful appliances will not compensate for ignorance of the nature, position, variations, and interruptions of the substances the miner may be in quest of. . . . The practice of mining is no doubt surrounded by numerous difficulties; but it is astonishing how many of these may be overcome by an engineer thoroughly acquainted with the geological structure of his field, and ever on the alert to notice the nature, position, and direction of any changes that may occur in the strata through which he is driving."

The truths thus clearly and forcibly expressed by Dr. Page are so obvious, and so generally acknowledged, that neither explanation nor proof is needed here; and they are a sufficient justification for introducing geological considerations somewhat largely into the present work. Geology must be held to be the foundation upon which the science of mining engineering rests, and as such it claims the first place in a work that pretends to build up the superstructure.

A rock has been defined as a mass of mineral matter consisting of many particles, either of one species of mineral, or of two or more species of minerals, or of fragments of such particles, which may or may not resemble each other in size, form, or composition. Under the term "rock," the geologist includes all large masses of mineral matter, whether the constituent particles of such masses be agglutinated and strongly coherent or not. Thus, in this sense, loose sand and clay are rocks, and in treating of them from this point of view, they are so denominated. The question of the origin of rocks is not only a very interesting one, but it is of great practical importance, inasmuch as its true determination enables us to solve many other problems that have a direct and immediate bearing upon matters that the mining engineer has constantly to deal with. Hence it will be necessary to take a brief view of the agencies and processes by which rocks have been produced.

THE ORIGIN AND CLASSIFICATION OF ROCKS.—It is an obvious fact that in bodies possessing a crystalline structure, the particles of which the crystals are composed must have been free to move and to arrange themselves in the positions due to the nature of crystallization. In other words, they must have been deposited from a fluid state. Such a state can be produced by only two agencies, heat and water, the former of which causes fusion, and the latter solution. To one or the other, therefore, of these agencies, the origin of every kind of rock must be referred, and according as the fluid state was due to the action of fire or of water, the resulting rock is classed as igneous or aqueous. The determination of the agent that has operated to produce a given rock rests upon certain well-known chemical facts. The crystalline particles of which an aqueous rock is composed must consist of minerals which are soluble in water at ordinary temperatures, since otherwise they could not have been deposited from their solutions. If, on the contrary, those particles consist of insoluble minerals, their fluidity must have been caused by fusion. To the latter class belong the silicates, and hence rocks composed of these silicates may fairly be referred to an igneous origin. Silica is, indeed, soluble in water containing carbonic acid gas, and this fact is sufficient to account for the deposition of crystals of quartz. But most of the natural silicates are practically insoluble in water.

In both these classes of rocks, we find slow gradations of texture, from those in which the component crystalline particles are large and distinct to others in which those particles have become too minute to be discernible, even with the aid of a lens. From this fact we may fairly infer that what is true of the crystalline rocks is also true of the compact rocks of the same mineral composition, and that therefore compact limestone, for example, has been consolidated from solution, and the compact silicates from a state of fusion.

The crystalline rocks, whether of igneous or of aqueous origin, have been produced by chemical action, and are therefore frequently described as chemical rocks. But the latter of the two great classes of rocks, namely, the aqueous class, contains another large and very important kind, which owe their origin to other agencies. In examining these rocks, we find the particles distinct, but not crystalline; or if they exhibit an internal crystalline structure, externally they will not possess the regular form of the crystal, having been subjected to attrition or fracture. These particles sometimes adhere to each other, in consequence of the great pressure brought to bear upon them by the superincumbent mass; but more often they are cemented together by some other substance, usually of a siliceous nature. The form of the particles, and their worn and rounded edges, show them to have been broken off some parent rock and transported by currents of water to their present sites. This derivative origin is obviously apparent in some rocks which are composed of pebbles and rounded fragments of rocks imbedded and compacted together in sand. But, as from this case of large and distinct constituents, there is every gradation down to that in which the particles have become too small to be discernible with a lens, we are justified in inferring that the compact rocks of this kind have been formed by the same agencies. The rock-forming action of currents of water is, indeed, constantly going on under our eyes. The rain carries away to the streams the particles loosened by the winds and frost; the streams convey them to the rivers, and the rivers roll them down to the sea, where they are deposited. Thus all the higher portions of the surface of the globe are being continually worn down, and the wasted material carried to a lower level. The particles borne away by the current being held merely in *mechanical suspension*, as it is termed, to distinguish it from *chemical solution*, are deposited as soon as the water assumes a state of quiescence. The

heavier bodies, as gravel, fall first; then follow the finer particles of sand; and finally the light flocculent mud, or clay. By processes such as these, lakes are silted up and become marshes and plains, and estuaries and narrow seas are converted into tracts of alluvial land. As the materials composing these rocks have been mechanically procured and transported, they have been termed *mechanical* rocks. Moreover, as they have been deposited from suspension, and arranged in regular layers, beds, or *strata*, they are often called *sedimentary* and *stratified* rocks, which terms, however, include the chemical rocks, being appropriately applied to the whole of the aqueous class.

There is yet another variety of rocks which have an organic origin, that is, they have been formed from living organisms. These organic constituents consist of fragments of animals or plants, which may be only slightly altered from their original condition, or altogether mineralized. In the former case, they are allied to the mechanical; in the latter, to the chemical rocks.

Upon consideration and examination, it becomes evident that many rocks, both of the igneous and aqueous classes, have undergone considerable and, in some cases, great changes since the time of their formation. The chemical actions and reactions that may be set up in a mass of rocks by the percolation of various fluids and gases, and by other agencies, and the mechanical forces generated by the pressure of superincumbent masses must have produced change, and such changes exhibit themselves in the *nodular*, *concretionary*, *crystalline*, *fibrous*, *veinous*, or other arrangement of the constituent particles. These transformed rocks have been classed by Sir C. Lyell as *metamorphic* rocks, and they constitute a large and important class, the changes due to the aforementioned agencies having been more general than is commonly acknowledged.

Thus we have three great classes of rocks—the igneous, the aqueous, and the metamorphic—under one or another of which every variety may be ranged, according to the nature of the agency by which they have been brought into their present state. Geologists acknowledge another class, denominated the *aerial* rocks, because the chief agent that has operated in their formation is the wind. This class is, however, unimportant for our present purpose.

Structure, Texture, and Hardness.—Structure is the manner in which the individual particles are built up or aggregated in the rock-mass. Thus the term relates more especially to the external aspect, the larger features of the arrangement of a rock, which can be properly studied only in cliffs, ravines, quarries, or other openings where the strata are exposed. In the aqueous or stratified rocks, the terms *stratum* or *bed* are applied to deposits of considerable thickness; *layer* or *band*, to a thin deposit holding a subordinate place among the other beds; and *seam*, to a rock of peculiar character occurring at intervals among a series of strata. Thus *seams* of *coal* occur among strata of clay and sandstone, and a *band* of *ironstone* exists in a bed of shale. The structure of an individual stratum may be *laminated*, *flaggy*, *fissile*, or *shaly*. Rocks, the component particles of which have been deposited from suspension in water, are made up of a number of thin layers, or *laminæ*, obviously the result of successive acts of deposition. Sometimes this lamination is very distinct, and the number of laminæ numerous, as many as fifty having been counted in one inch of thickness. The coherence between these laminæ varies greatly in different rocks. It would seem that when the depositions occurred in rapid succession, the coherence is greater than when long intervals elapsed between them. To this fact is no doubt due the structure termed flaggy, which denotes a greater tendency to separate between some laminæ than others, and thus to produce slabs of rock known as *flags* and *flagstones*. Any rock that has a tendency to split in any direction, whether in the line of bedding or otherwise, is described as *fissile*. Clay in its ordinary state is soft

and plastic; but when indurated and having a tendency to split in the direction of its bedding, it is described as *shale*, and its structure as *shaly*. The term *slaty* is applied to rocks which, like roofing-slate, split up regularly, in lines generally transverse to those of stratification; while *schistose*, from the Greek *schisma*, a splitting, is properly applied to fissile rocks having a crystalline texture and irregular lamination, as mica-schist.

The structure of the igneous rocks is less varied than that of the aqueous rocks. When appearing as columns, as in the basalts of the Giant's Causeway, the structure is said to be *columnar*, or *sub-columnar* if the columns are not very distinct. In rocks that break up into large square-like blocks, as some granites and greenstones, the structure is described as *tabular* or *cuboidal;* but if the blocks have no regular shape, it is *massive* or *amorphous*. Some greenstones present a *spherical* or *globular* structure, termed also *concretionary*, from its apparent aggregation round a common centre. The spherical concretions vary from a few inches to several feet in diameter; on exposure to the weather, they exfoliate, like the coats of an onion.

Texture is the grain, or manner of arrangement of the component particles of a rock. Thus while structure relates to the external aspect, texture relates to the internal constitution of rocks, and must therefore be studied in their fracture. When made up of distinct grains, like sandstone, the texture is *granular;* if the grains have a uniform crystalline aspect, as in many statuary marbles, the texture is described as *saccharoid; oolitic*, when composed of round particles, as in oolite; *porous*, when open like pumice; *vesicular* or *cellular*, when full of small cavities, like certain kinds of lava; *fibrous*, when composed of fibres or filaments, like asbestos; and *acicular*, when the fibres are distinct and needle-shaped. The texture is described as *compact* when close and firm; *crystalline*, when composed of sparkling crystals; *sub-crystalline*, when the lustre is dull; *earthy*, when soft to the touch and dull in aspect; *glassy*, when possessing the appearance of glass; *porphyritic*, when detached crystals are disseminated through a compact base, or large crystals through a fine-grained base; and *amygdaloidal*, when the pores or vesicles become filled with a crystalline nucleus or kernel of any mineral, either by subsequent infiltration or during the process of consolidation, so that the dispersed crystalline patches look like almonds stuck into the mass. It must be remarked here that some structural arrangements affect even the most minute particles of a rock, and that therefore structure is occasionally found to pass into what is more commonly described as texture.

Intimately connected with the texture of a rock, and of great practical importance, is its hardness. The hardness of a mineral, and consequently of a rock into the composition of which any given minerals enter, is estimated by a conventional scale of ten degrees, assuming talc to be the lowest and diamond the highest in the scale.

Talc	1	Felspar (Orthoclase)	6
Gypsum	2	Quartz (Rock-crystal)	7
Calc-spar	3	Topaz	8
Fluor-spar	4	Corundum	9
Apatite, or phosphate of lime	5	Diamond	10

If, for example, a mineral can be scratched by rock-crystal, but which is itself capable of scratching felspar, its degree of hardness evidently lies between 6 and 7 of the scale, and may be represented by 6·3 or 6·8, according as it seems to approach felspar on the one hand, or rock-crystal on the other.

THE CHIEF ROCK-FORMING MINERALS.—The minerals that enter largely into the composition of

rocks are not numerous. The following are the chief; and the student of geology should early make himself familiar with the distinguishing qualities of each of these rock-constituents.

Quartz.—The mineral known as quartz is silica or oxide of silicon. The usual crystalline form of quartz is a hexagonal prism, pointed, when complete, at both ends by hexagonal pyramids. It is colourless when pure, and its streak is white. Its lustre is vitreous, sometimes inclining to resinous. It varies from transparent to opaque. The fracture is conchoidal; the specific gravity from 2·5 to 2·8. In its transparent crystalline form, the mineral is known as rock-crystal, which, in the scale of hardness, occupies the seventh place. One of the most important characteristics of quartz is the total absence of cleavage. It is infusible alone before the blowpipe; but with soda it fuses readily, with efflorescence, to a transparent glass.

Calcite or *Calc-spar.*—Next to quartz, calcite is the most abundant mineral in nature. This crystallized carbonate of lime, the general term for which is calc-spar or calcareous spar, occurs in a great variety of forms and in various degrees of purity. Clear, colourless masses, cleaving readily into rhombohedrons, are found in Iceland, whence the name of *Iceland spar* given to such cleaved pieces possessing well-marked double refraction. Pure calcite occupies the third place in the scale of hardness; its specific gravity is from 2·69 to 2·75. Lustre, vitreous to earthy, transparent to opaque; streak, white or greyish; cross-fracture, conchoidal. Besides the numerous crystalline forms known as calc-spar, calcite occurs saccharoidal as crystalline limestone which, when perfectly white, is statuary marble. When occurring in small spherical grains cemented together like the roe of a fish, it is known as *oolite.* Calcite effervesces strongly on the application of mineral acids. It does not fuse before the blowpipe, but shines with an intense light.

Gypsum.—Calcic sulphate or sulphate of lime occurs hydrated in nature, and is known as *gypsum.* This mineral, when calcined, forms the well-known plaster of Paris. It is found in all formations, but it is more especially abundant in the carboniferous, permian, and miocene. It is deposited during the evaporation of brine, and is produced by the action of sulphuric acid generated by the oxidation of sulphur or pyrites, or evolved from volcanic fissures. When crystallized, it is known as *selenite.* It also occurs laminar, fibrous, saccharóidal, and compact, mixed with carbonate of lime, clay, and sulphur of various colours, but usually white. The fine, fibrous variety is known as *satin-spar; alabaster* is a term applied to the saccharoidal and compact varieties, consisting of carbonate of lime and sulphate of lime, the former being distinguished as *calcareous,* and the latter as *gypseous* alabaster. Gypsum does not effervesce with acids. It turns white before the blowpipe, and crumbles; but is fused only with difficulty. In hardness it occupies the second place.

Felspar.—As a rock-constituent, felspar is a very important mineral. It enters largely into the composition of all the igneous rocks, and is variously coloured. Felspars are chiefly composed of silica, alumina, and potash or soda, or sometimes lime. They have been divided into two series, crystallographically, known respectively as *orthoclase,* straight cleavage, and *plagioclase,* oblique cleavage. The former are the potash felspars, the latter the soda and lime felspars. The whole of the felspars have been classified into ten series, as follows:—Potash felspars: *Adularia, amazonite, perthite, loxoclase.* Soda felspars: *Albite, oligoclase.* Lime felspars: *Andesin, labradorite, bytownite, anorthite.* Orthoclase and albite may be considered as acid felspars, in contradistinction to the anorthite or basic felspar. All other felspars are mixtures of these three. The specific gravity of orthoclase is 2·56; of albite, 2·62; and of anorthite, 2·76. This mineral occupies the sixth place in the scale of hardness. The cleavage of felspar is highly characteristic, one face of cleavage being perfectly

smooth, and another, nearly at right angles to it, somewhat less perfect. Orthoclase may be recognized from the other varieties by having the two cleavage planes at right angles to each other. Before the blowpipe felspar fuses alone with great difficulty to a blistered, turbid glass; with borax it dissolves slowly, forming a transparent glass.

Hornblende.—This mineral varies in colour from black to white, through numerous shades of green; but in its commonest forms it is either black or of a dark green hue. It is usually opaque and translucent. Hornblende is an important constituent of the igneous rocks; it generally occurs confusedly crystalline, forming with quartz "hornblende rocks"; with quartz and felspar, "syenite"; and with felspar alone, the numerous varieties of "greenstones." In hardness it varies between 5 and 6 on the scale of Mohs; it is therefore softer than felspar. Its specific gravity is, however, greater than that of either felspar or quartz, it being between 2·9 and 3·4. When breathed upon, hornblende emits a peculiar bitter odour.

Augite.—The mineral known as augite or pyroxene is, in composition, closely allied to hornblende. The crystals belong to the monoclinic system, the inclination of the inclined axis being 74°, and the angle ot the type prism 87° 6′, parallel to which it cleaves. In colour it varies from white, through various shades of green, to brown and black. The lustre is vitreous, inclining to resinous, and in some cases pearly. The lustre, colour, transparency, and hardness vary with the relative proportion of the metals calcium, magnesium, iron, and manganese which the varieties contain. The hardness lies between 5 and 6, and the specific gravity between 3·23 to 3·50. Thus the hardness is about equal to that of hornblende, but the specific gravity is greater. Chemically the augites may be classified into non-aluminous and aluminous augites. The former consist of meta-silicates of calcium, magnesium, iron, and manganese; and the latter, of those silicates, with an aluminous silicate. In the augites of both classes the magnesium is sometimes almost wholly replaced by calcium and iron. The common augites are chiefly black, or greenish and brownish black, and very lustrous, whence their name, from *auge*, lustre. Like hornblende, augites assume a fibrous structure. This mineral enters largely into the composition of the igneous rocks.

Mica.—The term mica (from *mico*, to glisten) is applied to several minerals having a different chemical composition, but possessing the quality of being easily cleavable into thin laminæ. This laminar structure is hence termed micaceous. Mica is mainly composed of silica, potash, and magnesia. Chemically the micas may be divided into non-magnesian and magnesian micas. The former are called potash micas, because they contain a larger proportion of potash than those of the latter class. Common mica, or muscovite, is remarkable for the size of the folia which may be obtained. In thin plates it is always transparent; but when the plates are thick it is opaque. The colours are white, grey, pale green, dark olive green, brown, and violet yellow. The hardness of mica lies between 2 and 3, and its specific gravity between 2·8 and 3·1. Mica constitutes the chief ingredient in the slaty rocks called "mica-schist"; it occurs as scaly crystals in granite, and, in minute scales, in many sandstones, giving them a silvery appearance. The mica ot the aqueous rocks is derived from the disintegration of granite. Sandstones containing this mineral have a foliated structure, and are described as "micaceous."

The Determination of Rocks.—Having described the several classes and kinds of rocks, it now becomes necessary to point out the means by which they may be recognized. For the purpose of examining and determining in the field any specimen of rock that may come under our notice, it is requisite and sufficient to be provided with an ordinary chipping-hammer, a pocket-lens, a knife, and a small bottle of dilute hydrochloric or other mineral acid.

The first step in the examination is to form, by chipping, two fresh surfaces as nearly as possible at right angles to each other for the purpose of ascertaining the texture. The subsequent steps will be determined by the results of this preliminary measure.

If the rock be a *compact* one, that is, if no crystals or grains are visible with the lens, it must be scratched with the point of the knife; when, if it scratch easily, it may be inferred that it is either an aqueous rock or a very much decomposed igneous one. A little dilute acid may next be applied to a small portion of the specimen; and if it effervesce freely, it may be pronounced *limestone;* if the effervescence proceed slowly, the rock may be a *magnesian limestone;* but if no effervescence is produced, it may be either *gypsum* or a *decomposed rock.* If considerable force is required to scratch the rock, it is probably a compact igneous rock; but if it does not scratch at all, but is merely marked by the steel, it is probably a purely siliceous rock, as flint, chert, or some other kind of quartz, and therefore of aqueous origin.

If the texture of the specimen to be examined be *granular*, it will be necessary first to determine whether the grains be *innate* crystalline particles, or water-worn like grains of sand. If distinctly rounded and water-worn, even if only one such grain be visible, the rock must be classed as aqueous. But cases will be sometimes met with in which the grains consist of broken crystals bearing hardly a trace of attrition, when the rock may be mistaken for one of igneous origin. If, however, these crystals consist of quartz, they are probably aqueous; and a careful search will usually disclose some grain or fragment, the present form of which is evidently due to mechanical attrition. In some igneous rocks there exist small globules of crystalline quartz having the appearance of pebbles; the observer should be on his guard against being led astray by such deceptive appearances. When the rock is made up of layers differing from each other slightly in form and texture, it may be inferred that the rock is sedimentary, and therefore aqueous; but such evidence, though strong, is not absolutely conclusive.

If the texture of the rock be distinctly *crystalline,* that is, if it be composed of innate crystalline particles, the question to be determined will be whether these particles consist of carbonates or sulphates, or of silicates; and the determination of this question will decide that of the origin of the rock; for, if they consist of silicates, the rock has been formed by igneous agencies; and if of carbonates or sulphates, it may with equal certainty be referred to an aqueous origin. To ascertain the nature of the crystals, the specimen should be scratched with the point of the knife; if it scratch easily, they will almost certainly be either carbonates or sulphates. Acid should next be applied to the scratched part: and if immediate and violent effervescence ensue, the rock is some kind of limestone. If of magnesian limestone, the effervescence will take place slowly, in which case also the rock will present a pearly appearance, and have a gritty feel. But if no effervescence be produced by the acid, it will probably be gypsum. If the results of the examination prove the crystalline particles to be neither carbonates nor sulphates, they must be silicates; and it only remains to determine the kind of igneous rock by ascertaining the nature of the minerals present, and the proportions in which they enter into its composition. This may usually be done either with the naked eye, or with the aid of a lens, by recognizing the minerals from their characteristic appearance, or by determining the angles formed by their facets, and thence the form of their crystals.

When the structure is platy, that is, when the rock has a tendency to split into thin plates, it may be either an aqueous rock, formed by successive depositions in thin layers, or a metamorphic rock. If of the former class, it will be soft or easily broken, and the lines of division will coincide

with the layers of different colour or texture, or with the grain of the rock. If of the latter class, it will probably be hard, and the plates, after separation, will be more or less firm and strong. If the rock be a slate or *cleaved* rock, the faces of the plates will have a dull and earthy appearance. But if it be a schistose, metamorphic rock, the texture will be crystalline or sub-crystalline, and the faces of the plates will possess a metallic lustre.

In fine-grained and compact rocks it will happen that the texture and composition cannot be discovered with a lens, and the rough methods described above will, in such a case, be of no avail. For the examination of these rocks, recourse must be had to the microscope. To prepare a rock specimen for microscopical examination, a thin slice is taken and ground smooth on one side, when this smooth surface is securely fastened with Canada balsam to a piece of plate glass, and the other side ground down until the requisite thinness and transparency are obtained. Thus prepared it may be covered with a plate of very thin glass mounted with balsam on the slide, care being taken to exclude all air-bells, and to remove all traces of the emery powder or other substances used in the grinding process. With a rock-section prepared in this way, we may, with the aid of the microscope, ascertain with precision the manner in which the different minerals are built into each other, and throw a flood of light upon the origin of a rock and the subsequent changes it has undergone. Points of structure which could not be discovered in any other way are, by this means, clearly revealed. This method of examination has been recently adopted to distinguish between augite and hornblende, two minerals that are very similar in appearance when occurring as minute crystals.

The foregoing methods of examination will not always enable us to determine what minerals enter into the composition of a given rock, nor inform us expressly of what elements the minerals themselves are composed. In such cases, recourse must be had to chemical analysis. Such an analysis every mining engineer ought to be capable of making; for not only does it open up to him fields of research of the highest interest, but it is of daily practical use to him, by enabling him to determine the relative age of rocks from their mineral composition, and their ability to withstand the disintegrating influence of atmospheric agencies, and hence their suitability to building purposes. The student who wishes to pursue this subject will find it carefully and fully treated in Bischoff's 'Chemical Geology.' The methods of field examination we have been describing may be studied in Jukes and Geikie's 'Manual of Geology,' to which excellent work we have to acknowledge our indebtedness for some of the facts and classifications given in the present chapter. The student is also recommended to examine and make himself familiar with the principal rock-constituents already described, so as to be able to recognize them in any kind of rock that may come under his notice.

In the determination of rocks, their *colour*, *streak*, *fracture*, and *specific gravity* afford assistance, and sometimes conclusive evidence, towards arriving at a correct decision. By colour of a mineral, is meant the hue which it possesses when first taken out of the earth; for exposure to the atmosphere may either obscure or totally change its natural colour. A more reliable test than the natural colour of a mineral is the colour of its "streak," produced either by scratching it, or by drawing it across a piece of white unglazed porcelain. Fracture furnishes an important test. There are three kinds of fracture, known as the *conchoidal*, or shelly, in which the fractured surface presents curved concavities resembling more or less closely those on the inside of a bivalve shell, as in flint and glass; the *even*, in which the fractured surface presents no minute elevations and depressions; and the *hackly*, in which the elevations are sharp or jagged, as in broken iron. The specific gravity of a mineral is of

very great importance as a test, and, in some cases, it is almost the only one to which recourse can be had without injuring the specimen. The determination of the specific gravity is effected by first weighing a fragment in the usual manner in a delicate balance, reckoning the weight in grains. The fragment is then suspended, by a fine thread from one of the scales, in a tumbler of water, and its weight taken again. Care must be taken to sink the specimen below the surface of the water, and to prevent it from touching the sides of the glass. The second weight is then subtracted from the first, and the latter divided by the difference; the result is the specific gravity.

THE IGNEOUS ROCKS.—The igneous rocks are, as we have previously pointed out, made up of minerals that are silicates. These minerals may be divided into two great classes, namely, silicates of magnesia, and silicates of alumina. The former constitute the hornblendic or augitic minerals, the latter the felspathic. The several varieties are due to an admixture of silicates of potash, soda, lime, iron, manganese, and other substances. There are, indeed, the micaceous minerals, to which may be assigned an intermediate place; but they must be considered as of minor importance. The felspars are the bases of the igneous rocks, and those kinds in which this mineral greatly predominates are described as felspathic rocks; while those in which hornblende and augite enter as important constituents are called hornblendic or pyroxenic rocks.

The igneous rocks have been classed, according to their age, as granitic, trappean, and volcanic. It is true that the relative age of the igneous rocks is not clearly defined like that of the aqueous rocks, since we have neither an unvarying order of superposition nor the presence of organic remains whereby it may be determined. Granite is sometimes found above the trap, and trap may exist among the older rocks; but generally, granite is the deepest seated, and is associated with the older strata, while trap occurs in those of the secondary epoch, and the volcanic varieties among those of a more recent period.

Granite.—Granite is the most easily recognized of all rocks. It is a compound of felspar, quartz, and mica; but the proportions of these minerals vary indefinitely. The felspar, however, never forms less than a third part, and rarely less than half the mass; generally it exists in a larger proportion. In some cases the quartz, and in others the mica, becomes so minute as to be hardly discernible. The texture of granite is highly crystalline; none of the crystals are water worn, and no trace is exhibited of deposition or stratification. The texture varies, however, in degree from the compact and fine-grained to the large and coarsely crystalline. The colours of granite are white, grey, and red; white when the felspar is pure white, and red when the felspar is flesh-coloured. The intermediate grey tints depend chiefly on the abundance and colour of the mica. The felspar of granite is usually orthoclase, and is then either flesh-coloured or white; but oligoclase often occurs of a greenish or greyish white colour. Oligoclase is distinguishable from orthoclase by its fine parallel striations. The mica varies greatly both in colour and in lustre. When silvery-white or golden-yellow, it is usually potash-mica; the brown and black varieties being magnesia-mica. The quartz is either colourless or white; cases may, however, occur in which the quartz has a dark-grey or brownish hue.

In granite the quartz is always visible; indeed, the existence of crystalline particles of quartz among crystalline particles of the other minerals constitutes its most essential character, the quartz being invisible in most of the trap rocks. A remarkable fact is, that though the felspathic and micaceous constituents frequently form perfect crystals in granite, quartz rarely does so; from which fact it may be inferred that the former were solidified before the latter.

Though the granite rocks differ considerably in colour, texture, and mineral composition, they possess several features in common which distinguish them from the later igneous rocks. They are more crystalline than any of the other varieties; they are never vesicular, cellular, or porous, like the traps and volcanic rocks; they exhibit less structure than the traps, being generally massive or cuboidal, and never columnar, a structure very common in the basalts and greenstones; and they are never amygdaloidal like traps, conglomerated or brecciated like trap-tuffs, nor scoriaceous like volcanic tufa. They seem to have been formed at greater depths or under greater pressure than either traps or lavas.

There are several varieties of granite which have been named according to the presence of accidental minerals. When hornblende takes the place of the mica the rock is known by the name of *syenite*, and when both mica and hornblende are present, the compound is called *syenitic granite.* Sometimes, as in the Alpine granite, talc is present. The rock, which then consists of orthoclase, oligoclase, quartz, mica, and talc, is in this case called *protogine*. *Graphic granite* is a variety distinguished by a peculiar mode in which the quartz is crystallized in the felspar, so as to produce on a cross-fracture of the quartz crystals the appearance of Arabic writing. *Hypersthenic granite* is a term applied to an admixture of quartz and hypersthene with scattered flakes of mica. *Pegmatite* is a coarse granite full of druses, and consisting essentially of orthoclase, which often occurs in very large crystals, quartz, and large plates of silvery-white mica. This variety occurs in veins or layers in other granitic rocks. When, in addition to the crystals composing the general mass of the rock, there are indiscriminately mingled through it larger and independent crystals of felspar, so as to produce a porphyritic texture, the rock is called *porphyritic granite*. Other varieties exist, but they are of little importance.

Trap Rocks.—The term *trap* or *trappean* is derived from the Swedish word *trappa*, stairs or steps, and was originally applied to those igneous rocks which give to many hills of the secondary epoch a terraced or step-like appearance. The term is now applied to all those igneous rocks which are neither strictly granitic on the one hand, nor distinctly volcanic on the other, and which, in point of age, are intermediate between the granitic and the volcanic rocks. The trappean rocks may be conveniently divided into two classes or families according to the minerals that enter into their composition, namely, the felspathic traps, which compose the more siliceous variety, and the hornblendic traps, under which head are ranged those of a more basic character. The felspathic family also includes two groups distinguished by similar qualities, and hence known as the acidic and the basic groups. The former consists of those rocks which contain orthoclase, with an excess of free silica. The rocks of this group are called felstones. The basic group contains those rocks which consist essentially of one or more of the basic felspars. The rocks of this group are called porphyrites.

"Felstone" is a designation that has recently been substituted for a variety of terms that had been applied to the same class of rock, such as compact felspar, felsite, eurite, petrosilex, and cornean, which terms are still in use among continental geologists. The rock thus designated is composed of an intimate mixture of orthoclase and quartz, and is compact, smooth, hard, and flinty in appearance. There are two varieties of felstone, distinguished by their colour; the pale green passing into a greenish white, and the blue or grey varying from pale to dark grey. Both of these varieties weather white. The weathered part, however, frequently exhibits ferruginous stains, sometimes becoming wholly brown, especially in the green variety. Some blocks that appear wholly white

have a small blue patch in the centre. The green variety is often very translucent at the edges; but the grey is commonly opaque. The fracture of felstone is generally smooth and straight; in some cases it is slightly conchoidal, and in some of the blue or grey varieties it may often be rough and splintery. The rock frequently splits into small slabs, and in the green variety into laminæ.

In the most compact varieties, small shining facets of crystals of felspar may be detected with a lens; these crystals become gradually larger and more numerous, until the rock becomes completely granular and crystalline. Small crystals of quartz are also occasionally present. Mr. Jukes remarks that in some felstones there are small globules of glassy quartz, in appearance like rolled pebbles, leaving round cavities in the rock when they are detached. These he believes to be crystalline *blebs* of quartz, formed during the consolidation of the rock.

Felstone in its commonest form is perfectly compact; when distinct and independent crystals of felspar are disseminated throughout a base of compact felstone, the rock is designated as porphyritic felstone, or felstone porphyry. If it happen, as it not unfrequently does, that the scattered crystals of felspar are of a different colour from the base, the rock is called porphyry, and is used as an ornamental marble. Usually the base is of a reddish colour, and the scattered crystals whitish or flesh-colour.

"Pitchstone" is a compact glassy rock, closely allied to the foregoing, and having a pitchy lustre and fracture, whence its name. It varies, however, in colour, from velvet black, through shades of impure green and yellow, to white. Its texture is sometimes porphyritic. This rock is also called Retinite.

"Minette" is a micaceous felstone, consisting of a felsitic base in which crystals of orthoclase and dark mica are disseminated.

"Clinkstone," or phonolite, is sometimes classed among the trappean rocks. But the clinkstones so described are probably only platy varieties of felstone, the slate-like fragments of which often emit a ringing metallic sound when struck with the hammer.

"Porphyrite" consists of a base of oligoclase, with crystals of the same mineral disseminated throughout the base, and a variable admixture of hornblende, mica, augite, and quartz; the two latter, however, but rarely. The texture of porphyrite is usually very close-grained, and, as its name implies, more or less porphyritic. Frequently the texture is amygdaloidal. In colour, porphyrite varies from white or pale grey, through various shades of red, lilac, and purple, to dark brown. The dark tints are the most frequent.

"Kersanton" is a form of mica-porphyrite; this variety contains hexagonal plates of mica disseminated through a greenish or grey base. Kersantite is another variety, containing a little hornblende.

The Hornblendic traps, frequently designated by their old name of "Greenstones," constitute a numerous and very important class of trap rocks. They consist essentially of a crystalline mixture of some plagioclase felspar with hornblende or augite. The felspar is usually oligoclase, but some more basic variety sometimes occurs. In some rocks of this class, augite or hypersthene is substituted for the hornblende. Compact and dark-coloured greenstone is very similar in external appearance to basalt. But if the weathered part be broken open and tested with acid, greenstone will almost invariably effervesce along the inner edge of the weathered portion. Like felstone, greenstone may become porphyritic in texture in consequence of one or other of its constituents forming distinct crystals in a compact base, or large crystals disseminated through a fine-grained crystalline base.

"Diorite" is composed of felspar, usually oligoclase, and hornblende. In texture it varies from the compact to a coarsely crystalline aggregate In colour it is generally of a dull green, varying from light to dark. There exist varieties, however, in which the felspar is very white and in great quantity, and in such cases the rock is white, speckled with dark green spots. It weathers to a dull dark brown.

"Diallage-rock" is composed of labradorite and diallage. Generally it is of a palish green or grey colour, but sometimes of an olive or greenish brown colour. Its texture varies from fine to coarse-grained, and in some instances it has a granitic, and in others a porphyritic appearance. In Britain it occurs associated with metamorphic rocks.

"Hypersthene-rock" is a mixture of labradorite and hypersthene. The labradorite is green with glancing shades of blue and red, and the hypersthene is dark brown, inclining to black. In texture it varies from the fine-grained to the excessively coarse-grained. Mr. Jukes mentions the fact of having seen a specimen of this rock in which the two minerals formed crystals as large as the fist. The fine-grained variety resembles diabase or aphanite.

"Melaphyre" is a term applied to several varieties of dark, compact, heavy rocks of igneous origin. The following description of melaphyre is given by Senft. "An indistinctly mixed rock, of a dirty greenish-brown or reddish-grey, or greenish black-brown, passing to a completely black colour, hard and tough in the fresh state, in which appear crystals of reddish-grey labradorite, with magnetic titaniferous iron, and commonly with some carbonate of lime, carbonate of iron, and ferruginous chlorite, sometimes in crystalline grains, sometimes compact or earthy, sometimes porphyritic or amygdaloidal."

"Diabase" is a name given by German petrographers to a crystalline-granular mixture of labradorite and augite with chlorite, and sometimes with an impregnation of carbonate of lime. This rock occurs in the Silurian, Devonian, and Carboniferous systems of Germany.

"Aphanite" is a name applied to the compact, close-grained varieties of greenstone. By some writers it is restricted to the dioretic rocks, by others it is extended also to the compact diabases.

"Wacke" is a name given by German petrographers to decomposed forms of basic igneous rocks.

The foregoing descriptions relate to the crystalline traps, which constitute by much the larger portion of existing trap rocks. But there is another kind that owe their origin to mechanical agencies. The detritus in the form of dust and gravel, with large blocks or bombs ejected from volcanoes in past ages, falling into water, was rearranged, and became consolidated into rock. Also large masses of igneous rocks exposed to the action of atmospheric and aqueous agencies became disintegrated, and the detritus, finely comminuted, was deposited in beds to form new rocks. The trappean rocks that owe their origin to such agencies are analogous in character to the conglomerate of the aqueous rocks, and they are distinguished from the crystalline rocks from which they are derived by the name of *Fragmental Rocks.*

The fragmental trappean rocks are divided into two groups—Tuff, or trap-tuff, and Trappean Breccia or conglomerate. Under the term "tuff" are included all the fine-grained varieties. These varieties are named according to the nature of the rock from which they have been derived. Thus we have Felstone-tuff, Porphyrite-tuff, and Greenstone-tuff, each of which is distinguished by the qualities characteristic of the parent rock. This remark applies also to the Breccias, which consist of angular fragments embedded in a paste of the same materials. When the fragments are rounded, the rock is called trap-conglomerate.

The Volcanic Rocks.—The volcanic, like the trap rocks, may be divided into two families, the acidic and the basic; the former being distinguished as trachytic, and the latter as doleritic. The trachytes, so named because they have a rough prickly feel when handled, are composed principally of a felspar rich in silica, as orthoclase, and are usually light-coloured. The following are the chief varieties.

"Trachyte" proper is generally of a pale grey colour; but the tint may vary to a dark grey, and, in consequence of the presence of iron, to a reddish shade. The texture is either compact or fine-grained, and some varieties become highly porphyritic.

"Pearlstone" consists of a mass of rock, or base, in which are contained a number of globules, varying in size from that of a coarse grain of sand to that of a hazel-nut, easily detachable from the mass, and having a vitreous aspect and a pearly lustre, whence its name. The rock is of various tints of grey, yellow, brown, and red.

"Phonolite," or "clinkstone," is a compact, greyish rock, weathering white externally. It possesses the quality of splitting into thin plates or slabs, in such a degree that it has frequently been used for roofing-slates. These slabs, when struck with a hammer, emit a clear metallic ring, whence the name of the rock. Sometimes the structure is perfectly columnar, in which case the columns split across into slabs.

"Andesite," so named from its occurrence in the Andes, is a trachytic rock of various degrees of compactness, and a coarse conchoidal fracture.

"Obsidian," or volcanic glass, is closely allied to pearlstone, the difference being due merely to a more rapid cooling from the molten state. Its composition is very variable, depending upon that of the rock from which it has been melted down. In colour, obsidian is generally black, and opaque in mass, but appears grey and translucent at the edges. It is remarkable for its perfectly conchoidal fracture and its sharp cutting edges.

"Pumice" is a vesicular or porous rock, produced by the solidification of the scum or froth of a molten mass, and closely allied in composition to obsidian. In colour, it is of a pale yellowish-grey, passing into grey, brown, and black. It is very brittle, and its fracture is uneven and conchoidal. Owing to its porous character, pumice floats in water; but its true specific gravity when pounded is 2·3.

The doleritic or basic volcanic rocks are of a dark green or black colour, and are composed of a triclinic felspar and augite, with magnetic or titaniferous iron and olivine. They contain a larger proportion of the heavier bases than the trachytes. There are three principal varieties of these rocks, known as dolerite, anamesite, and basalt: varieties that are due rather to differences of texture than of composition.

"Dolerite" is composed of labradorite and augite, with some titaniferous or magnetic iron, and often a little carbonate of iron and carbonate of lime. The labradorite forms white or light grey tabular crystals, and the augite black columnar ones. Both can be distinguished by the naked eye. The magnetic iron exists as small octahedral, scarcely visible grains, which may be removed by the magnet when the rock is pounded. Olivine occurs as minute granules of a yellowish or greenish tint, and constitutes the most characteristic accessory mineral in dolerite.

"Anamesite" is simply a fine-grained dolerite, in which the component minerals are so intimately blended that they cannot readily be distinguished. It occupies an intermediate place between dolerite and basalt. In colour it is dark green, or greenish or brownish black.

"Basalt" is by many writers included among the trap rocks; but in composition and texture it is more allied to the volcanic class. It is a compact and hard rock, frequently columnar in structure, and of a dark or altogether black colour. It is composed of labradorite, augite, and titaniferous iron, usually with an admixture of small spherical crystals of olivine and of carbonate of iron and lime. Besides the ordinary compact texture, basalt may assume porphyritic, amygdaloidal, slaggy, and earthy textures.

In the South Staffordshire coal-field, dykes of doleritic rocks are intruded among the coal seams, and in these cases the rock is white and of an earthy texture. Such dykes are locally known as "white rock;" in external appearance they closely resemble sandstones.

The volcanic rocks have also their fragmentary accompaniments. These are formed in precisely the same manner as the fragmentary trap rocks. The chief varieties are: Scoria, rough cinder-like fragments of lava; Bombs, which are more or less spherical forms, frequently hollow, that owe their shape to having been thrown into the air while in a liquid state; Volcanic Agglomerate, an unstratified mass of volcanic stones; Volcanic Breccia, a stratified mass of angular volcanic stones; Volcanic Conglomerate, a stratified mass of rounded volcanic stones; and Volcanic Tuff, named after the variety of rock of which it is composed, as trachyte-tuff, doleritic-tuff, and basalt-tuff.

The following is a tabular view of the igneous rocks:

Granitic Rocks.

Granite, Syenite, Pegmatite, Protogine, Graphic Granite.

Trappean Rocks.

Felspathic.	*Hornblendic.*
Felstone, Pitchstone, Clinkstone, Minette, Kersanton, Kersantite, ——— Porphyrite. Felstone-tuff and Porphyrite-tuff, with Breccias and Conglomerates.	Diorite, Diallage-rock, Hyphersthene-rock, Melaphyre, Diabase, Aphanite, Wacke. Greenstone-tuff, with Breccia and Conglomerate.

Volcanic Rocks.

Felspathic.	*Augitic.*
Trachyte, Pearlstone, Audesite, Phonolite or Clinkstone, Obsidian, Pumice. Trachyte-tuffs and Breccias.	Dolerite, Anamesite, Basalt. Doleritic-tuffs and Breccias.

We have already pointed out that the igneous rocks may be classed into two divisions—the acid or siliceous rocks, and the basic rocks. The former contain a larger proportion of silica than the latter, the difference in the proportions being generally 7 to 5. This difference is often of great importance in determining the variety of a rock by chemical analysis, and is therefore worthy of careful note. Durocher, in his 'Essay on Comparative Petrology,' gives a table, which shows at a glance the limits and means of the proportions of the several substances that enter into the composition of the rocks previously described. This table, which will be found to be of practical use, is given in Haughton's 'Manual of Geology.'

Mode of Occurrence of the Igneous Rocks.—The igneous rocks differ widely in their mode of occurrence from the aqueous rocks, and this difference is often made the distinguishing feature of the

class, by describing the latter as stratified and the former as unstratified. These two great classes of rocks must, with respect to their mode of occurrence, be viewed as radically different, since the aqueous rocks have been *deposited from above*, while the igneous rocks have been *erupted from below*. The eruptive character of the latter must be constantly borne in mind when considering their relative position and form, both with respect to the other rocks and with respect to each other. Having been upheaved at various periods by internal forces, they may occur in any situation and form possible under such conditions, and in no others. Thus, having determined that a given mass of rock is of igneous origin, we are enabled to predicate concerning it, in some respects with certainty, and in others with a high degree of probability.

The several modes in which igneous rock may occur have been described as—eruptive, disruptive, intrusive, interbedded, and overlying, according to the effect produced on the aqueous strata, and the consequent positions assumed. These differences in the mode of occurrence are shown on Plate I. When an upheaval ot molten rock takes place beneath a mass of stratified rocks, it is evident that the former may penetrate the latter in either of two ways. It may force its way directly upwards through the strata by disrupting them, or it may force its way upward through some strata, and then intrude itself along the lines of division between other strata. In either case, on reaching the surface, it may spread itself out and form a bed that may subsequently be covered up by new deposits. The nature of the outlet through which the rock escapes, the position of these outlets, and the volume of rock ejected, may be such as to occasion the formation of huge amorphous masses, the boundaries of which at the surface will be more or less indeterminate. Such eruptive masses are shown at A, in Fig. 1. When an upheaval of igneous rock produces a disruption of the overlying strata, the line of disruption may extend to a great distance, and it is clear that this line will be that of least resistance. Frequently we may determine what the lines of least resistance were. They may have been lines of fault or fracture, lines of valley, or of some particular formation. The fissure being filled with the molten mass, a dyke is formed, extending vertically from the fundamental rocks to the surface, and horizontally to a greater or less distance along the line of least resistance. Such a dyke is shown at B, in Fig. 1. These dykes are very numerous, and in some coal-fields constitute a serious obstacle to mining operations. They vary in thickness from 6 inches to 70 feet or more. They ascend vertically through the rocks they traverse, or at a very high angle, like walls, a remarkable feature in them being the singular evenness of their sides. Usually the sides are as parallel as those of a wall of masonry, and much smoother on the face. In most cases, the ends of the strata next the dyke are upturned, and sometimes otherwise distorted; but instances occur in which they have not been thrown out of position, and if the dyke is intruded along the bottom of a trough, the strata may dip to the dyke on both sides, as shown in the figure. In almost every case, those portions of the strata which are in contact with the dyke will be altered, and the alterations will be such as would be produced by heat. Sandstones are hardened; sometimes in such a degree as to convert the rock into a quartzite. Shale is likewise hardened, and converted into a kind of porcellanite, or flinty slate. Coal is greatly altered, being converted into soot close to the dyke; charred cinder, or "clinker," a little farther away; and "blind coal," or a form of anthracite, at a still greater distance.

When, as was very frequently the case, the line of least resistance was along the divisional planes of stratification, the igneous rock was intruded along these planes, where they form a sheet or bed, varying in thickness from less than a foot to several hundred feet. Such beds lie regularly

and conformably between the strata, as if they formed an original part of the series. Frequently, however, they do not lie wholly along the same line of bedding, but cut across a stratum at intervals, and continue along the next divisional plane. The same changes in those portions of the strata that are in contact with the intruded rock occur here as in the case of a dyke. Intrusive sheets are shown at C, in Fig. 1. In order to ascertain with certainty whether an intercalated sheet of igneous rock be intrusive, it is necessary to examine the aqueous rock above, which, if the former has been intruded beneath it, will exhibit unmistakable marks of the action of heat. If no such marks exist, the igneous mass must be regarded as interbedded. As coal-seams offer less resistance than the more compact and refractory rocks, where the former exist it will be found that the intrusive rock has been intruded along them. In such cases, besides the change produced in the coal, the intrusive rock itself is altered in a manner that has been already described.

Frequently on reaching the surface, after disrupting the overlying strata, the igneous mass has spread out as a sheet or bed. Subsequent depositions having taken place, the igneous rock, which may extend over a large surface, appears as interbedded, as shown at D, in Fig. 2. The distinctive indications of an interbedded sheet are, the unaltered character of the overlying beds, and the absence of any derangement of the latter; the slaggy character of the upper and lower surfaces of the sheets, and the association of beds of trap-tuff. In some cases, these beds of igneous rock still lie upon the surface, having either been ejected in recent times, or exposed by the removal of subsequently-deposited strata by denudation. Such beds, an instance of which is shown at E, in Fig. 2, are distinguished as "overlying."

Besides the foregoing forms of occurrence, igneous rock may appear as veins traversing strata in any direction, and even igneous rocks of an earlier date. These veins are usually connected with a larger mass situate at no great distance.

The division of the igneous rocks into granitic, trappean, and volcanic series is, as we have already pointed out, more in accordance with their relative positions among the sedimentary strata than with any differences of a lithological character. Thus the granite was consolidated at a great depth beneath the surface, and cooled slowly under great pressure. Hence granite is the most solidly crystalline of all the igneous rocks, and is associated with the older strata. The volcanic rocks, on the contrary, have consolidated at the surface, a circumstance that has associated them with rocks of recent formation, and rendered their texture more or less open and scoriaceous. Between these are the trappean rocks, which have consolidated beneath the surface, but at a less depth than the granite. Hence these are more frequently associated with the secondary strata, and have a texture intermediate between the granitic and the volcanic. From these facts it may be inferred that granite will occur only as eruptive masses, trap as eruptive masses, dykes, intrusive sheets and veins, and overlying beds that have been exposed by denudation; and rocks of the volcanic series as dykes and overlying beds. And this inference is generally true.

Granite dykes and veins are sometimes found traversing masses of older granite, in which cases the more recent differs in texture from the older rock. Eruptive masses of trap usually consist of diorite, felstone, or quartziferous porphyry, and are associated with the Lower Silurian, Old Red Sandstone, and Carboniferous formations. They are generally compact in texture, but sometimes, as in Wales, amygdaloidal. Occasionally they are columnar in structure. Trap dykes traverse all formations. They usually consist of dolerite, melaphyre, or diabase, but sometimes of diorites, and, still more rarely, of some member of the felspathic family. The texture of dykes becomes more coarsely

crystalline towards the interior. In some cases they are minutely amygdaloidal, the kernels being arranged in lines parallel with the sides of the dyke. These lines of kernels are most marked along the centre of the dyke, and they decrease in number and in the size of the kernels as they approach the outside. In dykes of dolerite, the compactness towards the outside is such, that to a depth varying from that of a mere film to an inch, it passes into a black glassy substance called *tachylite*, resembling pitchstone in appearance, but distinguished from it by being quite basic in character, pitchstone being highly siliceous. This glassy film is probably due to the rapid cooling of the mass where it came in contact with the surrounding rocks. Generally dykes are traversed by two sets of joints, one crossing the dyke from side to side, the other running parallel with the length. This is especially the case with dolerite, in which the longitudinal series are more strongly marked. A common feature in dykes of dolerite or basalt is the columnar structure. The columns are always at right angles with the cooling surface, and therefore in dykes they will strike inwards from the sides towards the centre. Sometimes the columns do not reach the centre, and when they do, they do not always meet symmetrically. All the varieties of the crystalline trap rocks occur as intrusive sheets. Usually they have an amorphous internal structure, that is, they are divided more or less irregularly by joints. Sometimes, however, they are columnar, and in a few instances of compact felstones, of a rudely fissile character. In texture they are frequently porphyritic, especially those of the felspathic family, and occasionally they are amygdaloidal. As in dykes, the central portion is more coarsely crystalline than the outside. When in contact with highly ferruginous or calcareous rocks, the sheet is frequently veined with hematite, calc-spar, or serpentine, from the infiltration of the iron or lime. And when, as we have previously mentioned, it has been intruded among coal seams, it is converted into a soft white clay to a depth of several inches. Hence, if it be intruded along the parting of a coal seam with a thickness of only a foot or so, it will be changed throughout. Interbedded and overlying igneous rocks, having consolidated at the surface, differ in texture from intruded masses. The latter increase in compactness from the centre outwards, while the former increase in compactness from the outside towards the centre. The upper and lower surfaces of interbedded sheets are slaggy, the interior being more or less amygdaloidal and crystalline. The vesicles in which the kernels are contained are elongated in the direction of the flow; and this is especially noticeable along the top of the bed where the velocity was greatest. All interbedded sheets possess a jointed structure. The joints are, in some cases, very irregular; but generally they are well marked in two or more sets crossing one another, and extending perpendicularly to the upper and lower surfaces of the sheet. When developed with great regularity, they give a prismatic structure to the rock, which may become perfectly columnar, as in the dolerite of the Isle of Staffa.

When thick masses of igneous rocks are interbedded in any formation, and inclined with the other members of that formation, its line of outcrop will constitute a range of rounded or conical hills, often with lines of sharp escarpment, and when a great series of such rocks lie flat, or nearly so, they produce plateaux, the edges of which are lines of precipice or terraced slopes.

The mode of occurrence of the fragmental igneous rocks has already been described.

The foregoing description of the igneous rocks are sufficient to enable the student to identify the principal varieties. Though as a coal-mining engineer he will have much less to do with this class of rocks than with the aqueous, yet it is not only desirable but essential to his success, that he make himself familiar with their characteristic aspects, their mineral and chemical composition, and their modes of occurrence. The igneous rocks are, in the fullest sense of the word, the primitive

rocks, for from these, directly or indirectly, most of the others have been derived. It is therefore impossible to fully understand the character and the origin of the latter without an intimate acquaintance with the parent rocks. Moreover, as disruptive and intrusive masses, trap occurs with great frequency among the seams of coal, producing those faults which interrupt the continuity of a deposit, and constitute a formidable barrier to further progress. In these cases a knowledge of the character and modes of occurrence of such rocks, as well as of the effect they produce in the strata through which they force their way, is of the highest value to the engineer in enabling him to determine the best means of dealing with the obstruction. To the mining engineer whose labours are directed to the extraction of the metals other than iron, the igneous rocks constitute the most important class, since it is with them that he will have chiefly to do. For these reasons, we have devoted more space to this class of rocks than their importance seems, at first sight, to justify.

The Aqueous Rocks.—The aqueous rocks are, as we have observed, derivative; that is, they have been formed from the debris of the igneous rocks. The agencies that have operated in their formation may have been chemical, mechanical, or organic, and they may be grouped under these three heads. But it seems to conduce more to precision and clearness of arrangement to divide them into three groups according to their chemical composition, and to subdivide these groups according to the agencies that have operated in producing them. Such a grouping will divide the aqueous rocks into Sandstones, Clays, and Limestones. The rocks of these three groups differ from each other, not only in chemical composition but in the conditions under which they were formed. The sandstones are coarse in texture, being composed of grains or quartz that have been subjected to the action of running water. It may therefore justly be inferred that these rocks have been deposited in water in a state of more or less rapid motion; and hence they indicate a coast line and shallow water. The clays consist of particles in a state of extreme fineness, such as could only be deposited from still-water. As a matter of fact, the fine particles of mud carried down by a river are borne far out to sea, while the heavier grains of sand are deposited near the beach. Hence we infer that the clays were deposited in deep water. The limestones consist of fine particles like the clays; but this fact is due to their being the result of chemical action. Limestone is held in solution in water by the presence of carbonic acid in it, and the deposition from the solution may take place in shallow as well as in deep water. Of course, like any other rock it may be worn down by the action of mechanical causes, in which case the particles, from their extreme fineness, would be carried far out to sea, and deposited in deep water. Thus we have, according to the conditions of their formation, the sandstone group deposited in shallow water, the clay group deposited in deep water, and the limestone group deposited either in deep or shallow water.

Sandstones.—Sandstone consists merely of grains of sand compacted together, either by simple pressure long continued or by the presence of some other substance acting as a cement. The grains consist chiefly of quartz, sometimes clear and colourless, sometimes dull white, but oftener yellow, brown, or red. The red colours are due to the covering of each grain with a film of peroxide of iron, which sometimes serves as a cement to bind the particles together. Frequently the iron exists as a silicate, in which cases the film will be green. In most sandstones the cement is more or less siliceous. The particles are generally distinctly water-worn, and may be seen, even in those of the finest texture by the aid of a lens, to be embedded in the cement. Chemical analysis shows the sandstones to be derived from granite by the mechanical agency of water, which washes away the

silicates, and leaves only the most highly oxidated portion of the granite, the quartz, to form the basis of the new rock.

The sandstones may be ranged under three divisions: the simple, the compound, and the conglomerates, or breccias. The simple sandstones are those which are composed of pure quartz; of these we have but few examples. The compound sandstones are composed of quartz with one or more of the other minerals found in the primitive granite, as felspar, hornblende, mica, and clay. When composed of quartz and felspar, the rock is termed a *felspathic sandstone.* The grains of felspar, which sometimes occur abundantly, are distinguishable by their dull white, yellow, or flesh colour, and their peculiar appearance. Mica is rarely altogether absent, and in many sandstones the flakes and spangles occur so abundantly as to cause the surfaces of the rock to glitter, and the rock itself to split into thin plates. These are called *micaceous sandstones.* Besides these varieties, there are *calcareous sandstones*, in which the cement consists of carbonate of lime, and *argillaceous sandstones*, which contain an admixture of clay. The latter appellation is, however, not very appropriate, nor is it often used. When occurring in a very coarse form, compound sandstones are called conglomerates. A conglomerate has been defined to be a sandstone in which there are large particles of quartz, slate, limestone, or any other rock, cemented together by a more or less siliceous cement. The fragments in conglomerate are most commonly quartz, quartz-rock, or some very siliceous substance. This arises partly from the greater abundance of siliceous mineral matters, and partly from the greater durability of quartzose substances and their mode of fracture. The size of the fragments varies from that of a hazel-nut to that of a man's head. The degree of consolidation also varies greatly. In those which have been consolidated by simple pressure, the pebbles may be removed by a slight blow with a hammer, while in others in which a cement occurs the pebbles are very firmly embedded. Conglomerates, though stratified rocks, often show but faint traces of bedding, and it is only when seen on a large scale that their bedded character becomes apparent. The essential idea of a conglomerate is that all the fragments should be rounded, a circumstance which shows that they have been exposed to the action of waves on the sea shore, or of rapid tidal currents in shallow water. When the imbedded fragments are not rounded, but are angular and irregular, the rock is called a breccia. Conglomerate is sometimes called *puddingstone*, from a fanciful resemblance to the fruit in a plum-pudding.

"Grit" and "gritstone" are terms applied somewhat vaguely to sandstone to denote that the particles are hard and angular, in other words "sharper," than in ordinary sandstone. This angularity of the particles is, however, not always a characteristic, since in the sandstone rock known as "millstone-grit" the particles consist of perfectly round grains, sometimes as large as peas, or even larger. The term gritstone is perhaps most applicable to the harder sandstones which consist almost entirely of grains of quartz, most firmly compacted together by the most purely siliceous cement.

"Freestone" is a term in general use, and it is applied both to sandstones and to limestones. It means a stone that works equally *freely* in every direction, or has no tendency to split in one direction more than in another.

"Flagstone" means a stone that splits more readily in one direction than in another, that direction being along the original line of deposition. These stones are usually sandstones, though very argillaceous; but in some cases they are rather indurated clay in thin beds than sandstones.

Among the materials of a sandstone, a considerable proportion of alumina may occur, thus

providing the constituents for the formation of clay. Hence it results that the passage from sandstones to shales and pure clay is an insensible one. The following terms are applied by miners to some varieties of sandstones.

Calliard or *galliard* is a northern term for a hard, smooth, flinty grit.

Catsbrain is a calcareous sandstone in which the rock is traversed by little branching veins of carbonate of lime.

Faikes is a Scotch term for a shaly or fissile sandstone.

Hazel is a northern term for a hard grit.

Peldon is a South Staffordshire term for a hard, smooth, flinty grit (the *calliard* of the north).

Post is a northern term for a bed of firm, fine-grained sandstone.

Rock is used generally to denote any hard sandstone.

Rotche or *roche* is generally used to denote a softer and more friable sandstone.

Rubble is rough angular gravel, either loose or compacted into stone.

Clays, or Schists.—The term "schist" is properly applicable only to indurated clay rocks having a tendency to split up into irregular plates, and to this use it is often restricted. But some writers are in the custom of employing the term to include all the varieties of clay rock, and it is in this extended sense that it is employed here. Perfectly pure clay is a hydrated silicate of alumina, and is known as "kaolin," or "porcelain clay." It is derived from the decomposition of felspar, from which the silicates of potash, soda, and lime have been washed away. It occurs abundantly in some granitic districts, where it is carried down by the streams and deposited in hollows. Hence the clays, like the sandstones, are derived from granite. As pure clay, however, they rarely occur. Usually they contain a considerable proportion of potash and soda, with a variable quantity of minute grains of quartz. Their composition is, indeed, exactly what we might have expected from a consideration of their origin. If a granite rock be finely divided by the action of water, some of its alkaline silicates will be washed away, but the greater part of the constituents will remain in very nearly the same proportion as before. Chemical analysis shows this to have been the case. Hence we must regard the clay group as formed of granite very finely divided, reduced in fact to an impalpable powder, and deposited over the bottom of the sea in deep water. The relation of the clay to the sandstones will now become apparent. Both have been derived from the granite, and deposited from suspension in water. But the heavy particles of quartz were first deposited to form sandstones, while the lighter particles of the other minerals in a finely comminuted state were borne farther out to sea, and slowly deposited in deep water. The particles of quartz, however, would be of various degrees of fineness, and the finest of these would be carried out and deposited with those that were to form the clay, and between the sandstone and the clay it is obvious that the gradation must be such as to render the passage from the one kind of rock to the other an insensible one.

The clays may be grouped in two divisions: the simple and the compound. The simple clays are those which are composed of clay only, that is, the clay which is formed by a minute and fine mechanical subdivision of the granite rocks. The compound clays are those which contain a notable addition of some other mineral, of which mica, talc, chlorite, and hornblende are the most important. These compound clays or schists are distinguished according to the mineral present, as mica schist, talc or talcose schist, chlorite schist, and hornblende or hornblendic schist. To these compounds we shall again refer under the head of metamorphic rocks. It is obvious that there can be no

conglomerate or breccias among the clay rocks, since the fact of their being deposited in deep water precludes the possibility of such formations.

"Argillaceous flagstone" is a term applied to an indurated sandy clay or clayey sandstone, which splits into thick slabs or flags.

"Clay-slate" is a metamorphosed clay having a superinduced tendency to split into thin plates, which may or may not coincide with the original lamination of the rock.

"Fire-clay" is a term applied to any clay capable of resisting great heat without slagging or vitrifying. This property is due to the absence of any lime or alkalies to act as a flux. It is probable that in good fire-clays the silica and alumina exist in just that definite proportion which, on the application of heat, would combine into a true silicate of alumina. Such clays abound in the coal measures.

"Fuller's-earth" is a term applied to a soft unctuous clay which, from its absorbent character, is capable of removing grease from woollens; whence the name. Any clay containing from 20 to 30 per cent. of alumina will act as fuller's-earth.

"Loam" is a soft and friable mixture of clay and sand, having but little adherence, and being permeable to water. Any mixture of clay and sand, which is neither distinctly sandy nor clayey, is called loam.

"Marl" is properly calcareous clay, which, when dry, breaks into small cubical fragments. The proportions of lime in a marl may vary from 10 to 60 or 70 per cent. When the clay predominates the mixture is distinguished as "clay-marl," and when the lime is the more abundant, "marl-clay."

"Mud" consists of the finely comminuted materials of some form of argillaceous rock, intermingled with vegetable and animal matter, borne down by streams and deposited over the bottoms of seas, lakes, and pools. The term is applied to such accumulations only while they are in an incoherent and unconsolidated state.

"Mudstone" is a name given to a fine, argillaceous, and more or less sandy rock, void of shaly lamination, and evidently consisting of consolidated mud.

"Pipe-clay" is a nearly pure clay, white and free from iron.

"Shale" is regularly laminated, and more or less indurated clay, which splits into thin layers along the planes of deposition. This laminated, or, as it is termed, shaly structure distinguishes it from beds of clay and marl. Clay is *massive* or *plastic*; marl is *friable*; shale occurs in leaf-like *laminæ*.

"Silt" is a geological term for the miscellaneous matter deposited in lakes, estuaries, bays, and other still waters. It may consist of mud, clay, and sand, or of distinct layers of these.

"Slate" is a term applied to argillaceous rocks, whose lamination, like that of roofing slate, is not produced by lines of bedding, but is due to a metamorphism called *cleavage*, which often runs at right angles to the planes of deposition.

As the shales alternate with the sandstones in the coal measures, this class of the clay rocks is the most important that the coal-miner has to deal with. Hence it is that, as in the case of the sandstones, he has adopted terms to distinguish the several varieties. The following are the most generally used:

Batt or *bass* is very fine shale containing a large proportion of carbonaceous matter, called by the geologist carbonaceous or bituminous shale.

Bind is the colliers' term for ordinary shale.

Blaes is the Scotch term for ordinary shale, such shale being usually *bluish*-grey. When lumpy the term is *lipey blaes.*

Bluestone is the name applied in Caermarthenshire to common shale.

Clod is the same as "bind."

Clunch is the name for a tough, more or less indurated clay, often very sandy, lying beneath the seam of coal.

Danks is the Scotch term for "batt."

Kelve, a south of Ireland term for "batt."

Metal is the same as "bind."

Pindy, a south of Ireland term, synonymous with "kelve."

Plate is the same as "bind."

Pounson is a dense soft clay underlying the seams of coal.

Shiver is the same as "bind."

Slig or *sliggeen* is a term applied in the south of Ireland indiscriminately to shale and slate.

Warrant is the same as "pounson."

Limestones.—Limestone is a term for rocks the basis of which is carbonate of lime. As the sandstones and the clays clearly owe their origin to the granite rocks, so it would appear that the limestones have been mainly derived from the later trap rocks. We have already shown that lime and magnesia are much more abundant in the traps than in the granites. Hence, as these became worn down by the action of water and decomposed by chemical agencies, the quantity of lime held in solution in the water would rapidly increase. This would ultimately be deposited as carbonate of lime, carbonic acid being derived from the atmosphere. There can be no doubt that, as a rock, the limestone is subsequent in point of time to the sandstones and the clay. Different varieties occur in the different geological formations; and hence, though it is difficult, and in many cases impossible, to distinguish between the sandstones or the clays of different epochs from mere lithological characters, an experienced geologist can, from such characters, readily determine the true position in the series of any given specimen of limestone.

The limestones may, like the sandstones, be divided into the simple, the compound, and the conglomerates, or breccias. The simple limestones are those which are composed either of pure, or nearly pure, carbonate of lime, or of carbonate of lime and magnesia. These may be subdivided, according to their texture, into crystalline, compact, oolitic, and magnesian limestones, though the latter term relates rather to mineral composition than to texture.

Crystalline limestone may vary from fine to coarse grained; from a fine pure-white rock, resembling loaf-sugar in texture, to a rough granular one of various colours. The former variety is known as *saccharoid limestone* or *statuary marble.* The structure of limestones may be either original, in which case it often happens that each crystal is a fragment of a fossil, or superinduced by metamorphic action on a limestone previously compact.

Compact limestone is hard, smooth, and fine grained, generally bluish-grey, but sometimes yellow, white, black, red, or mottled. Generally its fracture is conchoidal; but it may be sharp and splintery, or dull earthy. This variety will frequently take a polish, and it has been used as an ornamental marble.

Oolitic limestone, or oolite, is so called because its structure resembles that of the roe of a fish, the word oolite meaning *roe-stone.* In this structure the mineral has assumed the form of little spheroidal concretions, composed of several concentric coats, sometimes enclosing a minute grain of

some other mineral substance, and sometimes hollow. Oolite is generally of a dull yellow colour, but not unfrequently it is grey. The peculiar structure of this rock gives it the character of a freestone, that is, one that may be cut with equal freedom in any direction. Hence its value for building purposes. Bath and Portland stone are well-known examples of oolitic limestone. A variety of oolite in which the concretions are as large as peas is called pisolite, or peastone.

Magnesian limestone or dolomite consists of carbonate of lime and carbonate of magnesia. Many limestones contain a small percentage of magnesia; but the term magnesian is not applicable unless the rock contain 20 per cent. and upwards. The occurrence of magnesia in small quantity frequently gives a sandy appearance and gritty feel to an otherwise smooth and compact limestone. The term "dolomite" is used to distinguish the crystalline from the earthy varieties. True dolomite contains nearly equal atoms of carbonate of lime and magnesia; and though the crystals are sometimes very minute, the crystallization and the pearly lustre are generally very distinct. Its colour is ususally pale yellow, but blue, grey, white, and even black varieties not unfrequently occur. Dolomite is often full of cavities, varying in size from that of a walnut up to that of a man's head. Often it is completely disintegrated, and looks like mere sand; but when examined with the lens, the apparent grains of sand are found to be little detached crystals. Magnesian limestone appears to be, in many cases, a product of the gradual metamorphosis of ordinary limestone, carbonate of magnesia replacing carbonate of lime.

Compound limestones are those which contain a notable admixture of some substance other than carbonate of lime and magnesia; and they are named after the minerals with which they are associated. Thus, as in the case of the schists, we may have micaceous, talcose, chloritic, and hornblendic limestones. Frequently clay has been deposited with the calcareous matter, producing a variety to which the name of "argillaceous limestone" has been given. The presence of clay may be detected by the peculiar odour emitted when the rock is breathed upon. Some of the argillaceous compounds make a beautiful marble Sometimes the silica which was diffused through the calcareous mass, instead of separating as nodules or layers, has remained so diffused; in such cases the rock is distinguished as "siliceous limestone." Sand may also be present in considerable proportions, producing a compound known as "arenaceous limestone." This variety is commonly known as "cornstone." In like manner, carbonaceous matter, derived from decaying vegetables, or decomposing animals, may produce the black limestones, known as "carbonaceous" or "bituminous limestone." Sometimes the remarkable mineral serpentine may be present as veins and nests; in this case the rock, which is the *verde antique* of the ancients, is called serpentine limestone. Many limestones are named from their containing some peculiar variety of fossil, as *nummulite, clymenia, crenoidal* limestone, and *shell limestone* or *muschelkalk.*

Beyond the essential difference that limestone conglomerates and breccias must be composed of a limestone paste, enclosing some limestones, pebbles, or fragments, this division of the limestones is precisely similar to the corresponding division of the sandstones. Generally but few limestone pebbles are found in conglomerates containing sandstone pebbles. This is what might have been expected, since in the grinding process which takes place among the pebbles on a sea-beach, where conglomerate is formed, the harder destroy the softer. Frequently the fragments consist of trap or trap-tuff, and slate.

"Chalk" is a simple limestone, white and fine grained, sometimes quite earthy and pulverulent, sometimes harder and more compact. This variety is well known.

"Fetid limestone," or *stinkstone,* is a name given to those limestone which emit, when struck or

rubbed, a fetid odour, like that of sulphuretted hydrogen. The odour from some of the limestone quarries in the carboniferous limestone of Ireland may be perceived at the distance of a hundred yards, and is sufficient to produce nausea in the men at work.

"Fresh-water" or "lacustrine limestones" have a peculiar aspect, from which their origin may frequently be determined by mere inspection. Usually they are of a very smooth texture, and possess only a slightly conchoidal, and often an earthy, fracture. Their colour is dull white or pale grey. "Shell-marl" is a soft, white, and earthy form of fresh-water limestone, formed of an aggregate of shells and a variable quantity of clay.

"Gypsum" is a sulphate of lime, and often occurs in regular beds. Sometimes, however, it occurs in irregular concretionary masses, or as veins and strings in other rocks. Gypsum has already been described.

"Rottenstone" is a siliceous and aluminous compound, resulting from the decomposition of impure limestones by the action of the atmosphere. In many cases, where a ferruginous limestone decomposes, the calcareous parts are dissolved and removed, leaving a fine, pulverulent, porous mass of ochre.

"Stalactite" and "stalagmite" are terms applied, the former to those icicle-like incrustations of lime which form on the roof of caverns and fissures, and the latter to the same incrustations that form on the floor. They are produced by the dropping of water holding these rock materials in solution.

In the foregoing subdivision of the aqueous rocks into simple and compound, the latter have been named according to the mineral with which they are associated. But it must be borne in mind that in all these cases the mineral exists interstratified by mechanical action. Thus a compound clay consists of a layer of clay, a layer of the mineral with which it is mixed, a layer of clay again, and so on. So also a micaceous sandstone is composed for the most part of quartz divided into sheets or leaves by the interposition of plates of mica.

The Metamorphic Rocks.—The metamorphic rocks are sedimentary rocks that have undergone, at a great depth beneath the surface, a process of change called metamorphism, by which their constituent elements have been rearranged, and generally a crystalline texture produced. In some of these rocks the original mineral texture is still recognisable, while in others all trace of it is effaced, and a new texture and mineralogical composition has been developed. The agencies that have produced this change are mainly heat and pressure and chemical action; but it is probable that other agencies have operated of which we know but little. The metamorphic are the lowest of the aqueous rocks, and are consequently associated with the granite and the primary formations. Many changes have, however, been effected in more recent times; and hence rocks of a metamorphic character may be met with in any of the later formations. Each of the three groups into which the aqueous rocks have been divided has its metamorphic varieties; but the most important occur among the sandstones and the schists of which the older rocks consist.

Altered Sandstones.—The most important of the altered sandstones is gneiss. This rock consists of the same mineral ingredients as granite, namely, quartz, felspar, and mica. It differs from granite chiefly in this, that while the crystals of quartz and felspar are distinct and entire in the latter, in gneiss they are broken, indistinct, and confusedly aggregated. Moreover, gneiss never sends out dykes and veins into the contiguous strata, like granite, nor does it ever assume those structures which, being the result of cooling, are possessed by the igneous rocks. It is hard and crystalline,

and frequently exhibits curved and flexured lines of stratification. These lines of stratification, or the regular arrangement of its component crystalline particles in a certain parallelism, impart somewhat of a schistose structure, and in some cases they afford the only means of distinguishing the rock from granite, in hard specimens. As might have been expected, the gradations of composition and texture towards granite on the one hand, and towards mica schist on the other, are insensible. It should be remarked that the term "gneiss" is often very vaguely applied to signify any hard quartzose semicrystalline schistose rock for which no other appellation could easily be found.

"Quartz rock," or "quartzite," is a sandstone that has been altered and hardened by heat. It is compact, fine grained, but distinctly granular, often so divided by joints as to split in all directions into small, angular, but more or less cuboidal fragments. When examined with a lens, it is seen to be composed of rounded grains imbedded in a purely siliceous cement. In colour it is generally of some shade of yellow or white. Occasionally it occurs red, and more rarely green. Quartzite is frequently confounded with vein quartz, from which, however, it may be distinguished by its granular structure.

"Greywacke" is a name given to certain forms of altered sandstones, consisting of a compact aggregate of grains of quartz, felspar, and mica, cemented by a siliceous, argillaceous, or felspathic base. The compact character of this base, and the way in which the grains often appear to pass into it, constitute a distinguishing feature in this rock. In colour it is generally of some shade of grey; but it may be brown, red, or blue.

Altered Clays.—The compound schists, which have already been described, are metamorphic. Mica schist occupies, however, so important a position that it deserves special mention under this head. It is composed of alternate layers of mica and quartz, the former consisting of small flakes firmly compacted together. The structure is often minutely corrugated or crumpled. Usually the separation of the layers coincides with the original bedding, but in some cases it may be independent of the bedding. Mica schist passes by insensible gradations into micaceous sandstones.

"Clay-slate" and "flinty-slate," or "Lydian stone," are also metamorphic rocks, the peculiar cleavage of the former being a superinduced one, and the characteristic flinty feature of the latter being the result of contact with a mass of fused igneous rock.

Altered Limestones.—The crystalline structure of some limestones is due generally to a metamorphic cause. That this cause was heat acting in conjunction with pressure has been proved by the experiments of Sir James Hall, who by heating chalk under such a pressure as would prevent the escape of the carbonic-acid gas, succeeded in converting it into a hard crystalline marble. The chalk of the north of Ireland is thus changed in many places by the intrusion of trap rocks. Among the altered limestones must be classed saccharoid marble and dolomite, the latter being in most cases, if not in all, the result of carbonate of magnesia replacing carbonate of lime. Serpentine has also a metamorphic character.

In the foregoing description of rocks, their mineral composition, their structure and texture, their colour, and all other distinguishing features they may possess, have been fully and clearly pointed out for the purpose of enabling the student to recognise any specimen that he may meet with. The importance of this power of distinguishing rocks will be evident when it is borne in mind that such peculiarities of composition, structure, and texture, or the presence of a pebble, fragment, or peculiar mineral, often furnish the only means of identifying strata very widely separated.

Formation of Rock-Beds.—The aqueous rocks have been formed, as already stated, by the

deposition of mineral matters from suspension or solution in water. This deposition has not been a continuous act, but a succession of acts, between which intervals of varying length have intervened. The non-continuous character of the act of deposition is only what we might have expected from the nature of things. It is only after heavy rains that streams become turbid with suspended matter, and though large rivers bear down to the sea a considerable quantity of matter in the most tranquil seasons, the quantity varies greatly at different periods. Also the velocity of a river varies with the volume of water to be discharged, and hence the turbid waters of a swollen river will be carried farther out to sea than those of a season marked by a more sluggish current. Other causes of turbulence, too, have operated to render the deposition of sediment fitful and irregular. The consequence to the formation of rock-beds of the want of continuity in the act of deposition is that all rocks so formed are divided into thin layers or *laminæ*. Each of these layers marks a separate act of deposition, the materials thrown down on each occasion having in some degree consolidated before the next deposition began. It is not, however, necessary to assume a total suspension of the act of deposition to produce these layers. A marked retardation of the act for some time, during which time the particles of the deposit would be finer as well as fewer, would still have this effect. But two layers separated by a period of retardation will coalesce more completely, and, therefore, adhere more strongly than two other layers separated by a period of total suspension. Hence it is that sedimentary rocks cleave along the planes of lamination, and more easily along some of these planes than along others. The length of the interval that elapsed between two successive deposits will also influence the degree of cohesion between the layers, that degree being less as the interval was longer. The absolute length of these intervals we have no means of ascertaining. These facts in the deposition of rocks satisfactorily account for the varying thickness of the laminæ of which they are made up, and the comparative want of coherence between the component laminæ of the *shales*, which were deposited in deep water, far from land.

But besides the *lamination* of rocks, there is their *stratification*, which may, however, be described as the same thing upon a larger scale. We have shown that a rock-bed is made up of thin laminæ laid one upon another by successive acts of deposition, which acts were separated from each other by varying intervals of time. But in no case was the interval a very long one. Long intervals, however, marked by a total suspension of the act of deposition, did sometimes occur. But these caused a complete separation between the last layer deposited and the next subsequent one, and thus a new bed was begun. These beds, which may vary in thickness from an inch to many feet, are designated as *strata*, and the divisional planes between strata are distinguished as planes of *stratification*. Very frequently the physical changes that interrupted the deposit of sediment altered the direction and force of the currents, and, consequently, the matter in suspension having been obtained from other localities, the new bed was formed of quite different materials. Hence we have a bed of sandstone, for example, resting upon a bed of clay, or a bed of limestone upon a bed of sandstone. As in the case of the laminæ, we have no means of determining the length of the interval that elapsed between the deposition of adjacent beds. It seems, however, a just inference to suppose that a longer interval intervened between the deposition of beds composed of different materials than between those of similar composition, since a long period of time must be assumed to produce the physical changes in the earth's surface by which the currents were altered. And when the change is from sandstone or clay to limestone, it becomes necessary to assume a still longer interval, as it was deposited in water in which all currents had ceased, a circumstance that implies great changes; and if, as

appears necessary in the case of all marine limestone, we assign an organic origin to the rock, we are compelled to allow a period sufficiently long for the production of the animals from whose secretions it is derived. Sometimes we have evidence that the interval was a long one, in the fact that two beds which are contiguous in one place, in another place are separated by other distinct beds.

The existence of such interstratified beds, leads to the consideration of the extent and termination of beds. The nature of the agencies by which rock-beds have been formed would lead us to suppose that they would vary as greatly in extent as in thickness, and such is found to be the case. Some beds cover only a small area; others extend over a wider surface; while others again are continuous over vast tracts of country. What is true of a single bed is also true of a group of beds, and hence we find "formations" abundantly developed in some localities, and altogether absent in others. As might have been expected from the nature of the agencies brought into operation in the formation of rock-beds, there exists an intimate relation between their extent and their lithological character. The finer particles of suspended matter were more widely and equally distributed than those of greater specific gravity. And hence we find that beds of clay are of greater extent and more equable in thickness than beds of sandstone, and beds of sandstone than beds of conglomerate. With respect to extent and regularity, the sedimentary rocks may be arranged in the following order:—Limestone, clay, sandstone, conglomerate. The way in which a rock-bed terminates is by thinning out in all directions; in some cases the thinning out is gradual; in others, it takes place more abruptly. Thus the form of a bed is that of a cake pared off at the edges. This is the natural form, and it is due to the mode of its formation. But all existing beds do not terminate on all sides in this way. Sometimes one side has been upheaved by subterranean forces, and the action of denudation has subsequently removed the thinner portions. In such cases the bed terminates abruptly at the surface. Or denudation without upheaval may produce the same effect on beds that have been deposited in an inclined position. When a bed thins off towards its termination its place is taken by the next adjacent bed, which, in like manner, thins off into it. This adjacent bed, may, and probably will, be of a totally different lithological character. Jukes has employed the diagram given in Plate I., Fig. 3, to illustrate this important matter of the termination of beds. The white beds are supposed to be limestones, which thin out into the adjacent beds of shale, shown in black. These beds of shale, of course, thin out into the limestone in the same way. Thus at the point where the thinning out of the limestones begins, the extremities of the shale-beds will appear, first as a mere parting, perhaps only half an inch in thickness, and then gradually thickening out to the full depth of the bed. In like manner the limestones will dwindle down to a mere parting in the shale. The latter thin out, on the opposite side, into the next adjacent beds, supposed in this case to be sandstone, and shown in the diagram by the dotted portion. The extent and termination of beds are well ascertained in coal mining, the operations of which consist in following the beds laterally.

Inclination of Rock-Beds.—The surface upon which a rock-bed was deposited was not always horizontal. Whenever a deposition has taken place upon an inclined surface the resultant bed is, of course, inclined to the horizon at the same angle as the surface upon which it was deposited. Moreover, as a bed was deposited over a very extensive area, the variations of surface may have been numerous, and hence, in different places, it may be inclined at different angles, and in different directions. But even where beds were originally deposited in the horizontal position, subsequent volcanic convulsions, accompanied with eruption of igneous rock, have frequently upheaved them

into an inclined position. Hence it arises that strata are, in most cases, more or less inclined. This inclination is called the "Dip" when viewed in the direction of the fall, and the "Rise" when viewed in the contrary direction. The "dip" is measured by the angle which it makes with the plane of the horizon. Thus a bed is said to dip at an angle of 14° when it makes that angle with a horizontal plane. It is seldom, however, that miners reckon the dip in degrees. With them it is customary to estimate it by comparing the horizontal distance with the fall. A dip of 14° would in this way be expressed as a dip of one in four, that is, in a distance of four, say, feet, measured along a horizontal line, the "fall," or deviation from that line, is one foot. In the same way an angle of 26° would be expressed as a dip of one in two. The direction of the dip is compared with the meridian. Thus a bed is said to dip N., N.E., N.N.E., &c., at an angle of 18°, or one in three.

When an inclined stratum comes to the surface, its edge is called the "outcrop," or "basset." Such a stratum is said to crop out to the surface, and the edge exposed is called its basset edge. Among miners these and other terms are used, such as "coming up to grass," "coming out to the day."

The line at right angles to the dip, that is, the line of outcrop along a level surface, is called the "strike." Like the direction of the dip, it is described by its line of compass bearing. As the strike is at right angles to the dip, when the direction of the latter is known, that of the former will be known also. Thus if a bed dips north or south, its strike will be east and west. But when the direction of the strike only is known, that of the dip does not necessarily follow, since it may incline to either side of the strike. Coal miners generally speak of the strike as the "level bearing," or "water-level" of a bed, because a drift or gallery driven through a bed at right angles to the dip must necessarily be on a true level.

Fig. 4, Plate II., shows a section through a group of highly inclined beds cropping up to the surface. The section is taken in the direction of the dip, and, consequently, at right angles to the strike. The beds, it will be seen, do not dip at the same angle on both sides of the fault. If we suppose the direction of the dip to be due east, that of the strike will be due north and south, in other words, the basset edges of these tilted beds run north and south.

It is seldom that the dip and the strike run in straight lines across the country throughout a great distance. On the contrary, both the degree and the direction of the dip are marked by extreme irregularity, the result of deposition upon an irregular surface, and the action of local upheaving forces. Hence it follows that the strike, or line of outcrop, may vary continually in direction, sometimes traversing the country in a curved line, or turning short back and continuing in a contrary direction, sometimes running in an irregular line, frequently breaking off in unexpected directions, and necessitating very careful observation to follow its course accurately. Often the beds dip in a certain direction for some distance and then rise in the contrary direction, forming a trough-like depression, or they may rise, and some of them crop out to the surface, while those beneath are bent over and continued downwards, forming a saddle-like elevation. In such cases, of course, the beds that crop out on one side reappear on the other. Sometimes the beds dip in all directions towards a central point, forming a basin-like depression, or again, though not so frequently, they may rise in like manner to form a conical elevation. These contortions occur on every scale of magnitude, from little crumplings apparent in a ditch to those displacements the radii of whose curves are measured by miles When the rock-beds consist of hard compact materials, such, for example, as crystalline limestone, the curves of upheaval or depression are usually regular, having frequently the appearance

of arches of masonry. But when the composition and texture varies, the beds are crumpled and otherwise distorted, in consequence of the varying nature of the lines of least resistance. An example of this is shown in Fig. 5, Plate II. When some of the beds consist of comparatively soft material, as shale and coal among sandstones, effects are produced of an important character to the miner. In some parts where the pressure was greatest the softer bed has been squeezed out into other parts where the pressure was less, until equilibrium was restored by the latter parts becoming extended. Hence the softer bed may be reduced in thickness in some places to an inch or less, or it may be pressed out altogether, the harder beds above and below it then coming into contact with each other. But in all such cases, all the material of the softer bed will be found farther on in an increased thickness of that bed. These accumulations are called by miners "pockets," and the squeezing out of the bed is described as the "nip."

When saddle-like elevations and trough-like depressions assume large proportions, they are spoken of as anticlinal and synclinal curves. Such configurations are shown in Fig. 8, Plate II., in which the beds are thrown into anticlinal curves at A, and into synclinal curves at B. The beds 5, 6, 7, 8 at A crop out to the surface on one side of the elevation and reappear on the other side, while the beds 1, 2, 3, and 4 are bent over in the form of an arch. At B, the beds numbered from 9 to 13 rest upon the former in the form of a trough. The imaginary line about which the beds may be supposed to be bent is called the axis of the anticlinal or the synclinal. This axis may be either horizontal or inclined. If it be horizontal, sections taken in any part will show the same beds. But if it be inclined, different sections will cut different beds. An excellent example of this, due to Mr. Jukes, of the Geological Survey, is given in Figs. 6 and 7, Plate II. Fig. 7 is a plan of undulating beds, the axes of the anticlinal and synclinal curves being inclined, in this case, dipping to the north, as shown by the arrows. It is obvious that, unless the surface of the ground slope with the axis, other beds must come in, arching over each other in the case of the anticlinal, resting upon each other in the case of the synclinal. Thus bed No. 4 will sink, or "nose in," as it is termed, under the new bed No. 5, which, in its turn, will "nose in" under No. 6, and so on. In like manner, in the synclinal bed, No. 14 will "nose out" over No. 13, No. 15 over No. 14, and so on. Hence, if we take a section along the line C D in the plan, such a section will appear as in Fig. 8, in which bed No. 4 forms the crest of the anticlinal, and bed No. 13 is the highest in the synclinal. But if another section be taken along the line G H, this section will appear as in Fig. 6, in which bed No. 7 forms the crest of the anticlinal, and bed No. 16 is the highest in the synclinal. It is of the utmost importance to observe carefully the inclination of the axes of the curves, especially to the mining engineer, who otherwise may be led to incur fruitlessly enormous expense. Jukes mentions a case that came under his notice in South Wales where a sum of 30,000*l*. was wasted in an abortive sinking for coal, the seam having cropped out across the axis of the synclinal a mile or more before reaching the spot where the shaft was sunk for it. A similar instance came under the author's notice in North Wales.

It has already been pointed out that the flanks of these curves may be more or less flexured according to the nature of the beds that have been subjected to the contorting forces. In some instances these flexures are carried so far as to produce actual inversion of the beds, a circumstance that is not unfrequent in the Belgian coal-fields. Such flexures may bring the same seam twice into a vertical shaft, and in such cases careful observation is requisite to avoid erroneous conclusions.

Alternation of Rock-Beds.—Sandstones, clays, and limestones occur either as separate

groups of beds, sometimes of great thickness, or interstratified one with another. The latter is the more common mode of occurrence. No general rule can be laid down for the association of the different kinds of beds with one another; but some degree of regularity is observable in the alternation of rocks of different textures. Thus beds of very fine and very coarse materials are rarely found resting upon each other. We should not expect to find shales, for example, resting upon conglomerate, but rather sandstones. So coarse sandstone is covered by a finer sandstone before the shale appears upon it. Beds of limestone are frequently separated from each other by beds of soft clay, or shale, and in such cases the latter material is commonly of a black or brown colour, and often very calcareous. Sometimes limestone alternates with sandstone, the sandstone in these cases being usually calcareous. But clay-beds more frequently alternate with both.

FORMATION OF ROCK-BLOCKS.—Besides the planes of deposition which separate one bed from another, there exist other lines of division running at right angles to these, and forming generally two sets, each of which runs at right angles to the other. These lines of division are called "joints." Sometimes each bed has its own joints, these apparently having been produced before the deposition of the next superincumbent bed. But in most cases the joints run through whole groups of beds. Sometimes, however, in passing from one bed to another, the line is slightly broken, a circumstance that may lead an inattentive observer to believe that the joints are distinct in each. A joint will pass through a pebble, dividing it as cleanly as if cut by a knife. In stratified rock, we have thus three planes of division: one horizontal, or parallel with the lamination, and two others perpendicular to the former, and at right angles to each other. Hence the bed will be divided into quadrangular blocks of various dimensions, and more or less uniformity of size according to the greater or less regularity of the joints. In the unstratified rocks the three planes of division are also frequently seen, another set of joints taking the place of the planes of stratification in the stratified rocks. Were it not so, it would be almost impossible to quarry such rocks. Frequently, however, the joints in unstratified rock are such as to produce prismatic instead of cuboidal blocks; and in such cases the joints traverse the rock with remarkable regularity.

Master-Joints.—When a set of joints run regularly parallel to each other throughout a considerable distance, they are called "master-joints" to distinguish them from the lesser joints which may extend for only a short distance. Sometimes such joints have wide intervals between them, and in these cases the resulting blocks are large. Or one set may be at greater intervals apart than the other, in which case the blocks may be of great length. The set of joints that run in the direction of the dip of the bed are distinguished as "dip-joints," and the set at right angles to those are called "strike-joints." The closeness of a joint is generally in proportion to the fineness of the texture of the rock through which it passes. Thus joints are more open in conglomerate than in coarse sandstones, in sandstone than in shale. In limestones, however, both open and close joints are found, some having been widened by the infiltration of acidulous water. Coal, from its peculiar nature, shows the most perfect system of jointing. Fig. 10, Plate II., from a sketch by Du Noyer, shows the two sets of joints traversing the planes of stratification. And Fig. 11, Plate III., shows a plan, constructed by F. J. Foot, of the Geological Survey, of such joints as they appeared on the surface of a horizontal bed of limestone several feet in thickness and 12 or 13 yards across, in County Clare, Ireland. Many of these joint-planes may be traced for several hundred yards.

The probable cause of rock-joints is contraction during consolidation. Clay, as is well known, cracks while drying; and molten materials shrink and crack on returning to the solid state. Joints

of precisely the same character as those occurring in nature may, indeed, be produced artificially. Some years ago an attempt was made in South Staffordshire to utilize blast-furnace slag by casting it in moulds to form blocks of building material. But in consequence of the joints developed in them, these blocks soon crumbled into small cuboidal fragments.

To the mining engineer and the quarry-master the subject of joints in rock is of the highest importance.

Slickensides.—The term slickenside is applied in mining to the smooth, striated surface of joints on the opposite walls ot a fissure, apparently produced by convulsive friction, and subsequently coated over with a siliceous or calcareous film or glaze by the passage of water or heated vapours. Slickensides occur more abundantly among igneous rocks, and in districts that have been much subjected to disturbing forces.

Cleavage and Foliation.—Cleavage is the tendency in rocks to split into thin plates in a certain direction. This tendency is especially remarkable in clay-slate, but it exists in other rocks. It is most perfect in the fine-grained kinds, which it divides very regularly into extremely thin plates or leaves. When the texture of the rock is coarse, the cleavage planes become faint, wider apart, and more irregular. These planes, when occurring in conglomerate, pass round the pebbles, leaving them sticking out from the surface, and do not pass through them as joint-planes do.

The direction of the cleavage planes is wholly independent of those of lamination, which it may, therefore, cross at any angle. In most cases the lamination is obliterated by the cleavage, the laminæ having been welded together by the agency that produced the cleavage. There is, however, a greater tendency in the cleavage planes to pass perpendicularly through the coarser than through the finer textures. Hence it happens that in passing from one bed to another the direction varies slightly. A remarkable feature in the direction of the planes of cleavage is that it is constant over large areas, and is unaffected by contortions; thus it may make any angle with the dip of the beds. But generally this steady direction, which, as it has been observed, may remain constant throughout a large extent of country, is coincident with the main axes of elevation, and hence with the strike of the beds.

The origin of cleavage is yet a disputed question. There can, however, be little doubt in the mind of one who carefully examines the question that it is due to pressure. It has been observed that fossils have been lengthened in the direction of the lines of cleavage as if they had been drawn out by a movement of the particles in that direction. This is precisely the effect that would be produced by pressure. Moreover, artificial cleavage may be produced in a substance by subjecting it to pressure under conditions that allow of its expansion in directions at right angles to the pressure. The planes of cleavage are always at right angles to the direction of the pressure that produced it.

The true dip of the planes of cleavage can be ascertained only at considerable depths, as very frequently superficial agencies have changed the dip for some distance beneath the surface.

Foliation is a term used to indicate a separation into crystalline layers of different mineral composition, such as we find occurring in mica schist, for example. Foliation, like cleavage, is a superinduced structure.

Faults and Dislocations.—One of the most important facts of geology to the coal miner is the existence of " faults." By the term " fault " is understood any interruption of the continuity of a stratum. The interruption may be complete, or only partial, and it may have been produced by one of a multitude of causes. One of these causes has been already described as the " nip." Besides

the term "fault," miners sometimes employ other expressions to signify the same thing, as "trouble," "check," and others which indicate the nature of the fault; these will be given as occasion requires.

Swells, Rolls, or Horses'-backs.—Sometimes a ridge of clay, thrown up by currents of water, has existed on the surface upon which deposition has subsequently taken place. Such ridges are sometimes from 6 to 8 feet high in the centre, and slope off gently on each side, and are known among miners as "swells," "swellies," "rolls," and "horses'-backs." One of these is shown at *a*, in Fig. 12, Plate III. It is evident that when a deposition takes place upon this surface, the continuity of the new bed or beds will be wholly or partially broken by the swell. This is shown in the figure where b, b', b'', and b''' are beds of coal. The beds b and b' end evenly against the swell on each side, or, as the miner expresses it, the coal in those beds is completely "cut out" for a distance equal to the thickness of the swell. The continuity of bed b'' is only partially broken; in other words, the coal is cut out through a portion only of its thickness. The evidence of the swell being anterior to the deposition of the higher beds lies in the fact that the latter exhibit no trace of disturbance. The beds cut out end evenly against the swell, and bed b''' in the figure, for example, is uncontorted.

Erosions, or Troughs.—Another kind of fault is caused by the existence of water-courses on the surface upon which deposition has subsequently taken place. The action of a stream is, by wearing away the soil, to cut out a bed for itself; and the breadth and depth of the excavation will be generally in proportion to the volume and the velocity of the stream, the softness of the strata over which it flows, and the length of time during which it has flowed. Hence the excavations due to erosions of this nature may vary in magnitude to an almost indefinite extent. When of considerable magnitude, the effects are classed rather as those of what is called denudation than erosion, the latter term being restricted to the effects of small streams. When the subsequent deposition took place, the hollows or troughs worn out by the stream were filled by the materials formed by the next bed in the manner shown in Figs. 13 and 14. The portion of the upper bed that fills the hollow is by miners frequently called the "horse," and it is spoken of in the same way as the "swell," as "cutting out" the bed beneath. As the softer strata were the most acted upon by the eroding force, coal seams have often suffered greatly. One of these erosions, in a coal seam in the Forest of Dean, has been described as extending over a considerable area, and showing branches in many places, such as would be produced by little tributaries flowing into it.

Besides the erosions caused by streams, others have been produced by currents of water of a different character. An example of these is shown in Fig. 15, Plate III. Bed No. 2 has become mingled by various currents with materials differing from those of the bed below. Bed No. 3 has been of greater thickness than it is now, and has been worn down in an irregular manner, previous to the deposition of bed No. 4. The latter suffered in the same way before being covered by No. 5. Erosions of this character possess no regularity.

Dykes.—Dykes of igneous rock are a frequent cause of fault, especially in certain districts. The character and mode of occurrence of dykes and their effects upon the surrounding rocks have been described under the head of Igneous Rocks.

Fracture and Displacement.—Fracture of the beds, and subsequent displacement of the several portions, constitute the most important and the most common kind of fault. It may easily be conceived that the forces which upheaved and contorted the beds in the manner we have already described, would also crack and break them through. As a matter of fact, such has been the case, and to such an extent that there is, probably, hardly a square mile of country wholly exempt from

faults of this character. In some cases, fracture alone was produced; but far more frequently displacements occurred, so that beds which were originally continuous now lie at very different levels on opposite sides of the fault. An example of this is given in Fig. 16, Plate III. Taking the coal seams as the most conspicuous, it will be observed that two beds are shown on the left-hand side of the fracture. On the other side, these beds have sunk down to a much lower level, bringing down nearly to their original level three other beds lying above them. Among miners, such a fault is sometimes called a "slip," or "slide," and the character of the displacement is described as a "downthrow," or "downcast." The expressions "upthrow" and "upcast" are employed—but, in many cases, incorrectly—to describe the position of the beds on the left-hand side of the fracture in the figure when viewed from the other side.

The amount of displacement, measured in a vertical direction, is called the "throw," and is expressed in feet, yards, or fathoms from the surface, when the latter is horizontal, and from a given horizontal plane, when the surface is irregular or inclined. Suppose, for example, the distance of the bed at *a* in the Diagram, Fig. 17, Plate IV., from the surface, or an assumed horizontal datum line A B, to be 100 yards, and the distance of the same bed from the same line to be at *b* 200 yards. The throw in this case would be described as a downthrow of 100 yards, without any reference to the horizontal distance A B, or the inclined distance *a b*, between the ends of the bed. The horizontal distance A B, which represents the extent of barren ground to be driven through, is, by the miner, frequently called the "width" of the fault. This width will vary with the angle of the fault. Diagram, Fig. 18, Plate IV., shows an inclined bed cut by two faults A B and C D, the angle of inclination of the latter being much less than that of the former. In this case, the throw of the fault A B will be measured by the line *a b*, and that of C D by the line *c d*. Also the width of the fault A B will be measured by the line A *o*, and that of C D by the line A *p*. Thus the nearer a fault approaches the perpendicular, the better it is for the miner. It is to be observed that, though the amount of throw is much greater in the fault A B than in C D, the position of the two portions of the bed X and Y is the same. Whence it will be seen that in faults inclined at different angles, or in beds lying at different angles, variations in the amount of throw will not be accompanied by a corresponding variation in the position of the beds at a little distance on each side of the fault.

Faults of dislocation differ from one another in *character* and in *effect*. The variations in character are mainly due to differences in the composition and structure of the rocks traversed by the fault. It is, indeed, sufficiently obvious that the alternation of hard with soft beds must influence the consequences of a fracture in no inconsiderable degree. The variations in effect are due to differences in the position of beds, and in the inclination, direction, and number of the lines of fracture.

When a fault runs through beds of shale alternating with thin beds of sandstone, the fracture may be merely a plane of division. In such cases, the surfaces of the fracture are frequently smooth and polished by the friction to which they have been subjected, and present the appearance known as "slickensides." When the beds traversed by a fault are composed of hard materials, as gritstone or limestone, a fissure of greater or less width will exist. If the line of fracture is an irregular one, which it usually is, the protruding parts on one side may rest against similar parts on the other, and in such a case the fissure will be closed up in some places and open in others. No doubt the irregularities thus produced have been greatly lessened by the wearing down of the protuberances by friction; but they are still remarkable. By open fissures, it must not be understood that the

spaces so formed are now empty. On the contrary, in most cases they have been filled up with the débris produced by the friction of protuberance against protuberance, or by materials subsequently brought into them. When hard and soft beds alternate, the fissure is generally closed at those parts where the soft beds occur.

Sometimes the beds end abruptly against each other without any distortion, as in Fig. 16, Plate III. But more frequently the ends have been bent, as in Fig. 19, Plate IV. In such a case, the beds are said to "dip to the downthrow," or "rise to the upthrow," a result which we should naturally expect a sliding of one bed over another to produce. But instances are by no means rare in which the contrary takes place, the ends of the beds having been crumpled up by the pressure of those on the opposite side of the fracture. No satisfactory explanation can yet be given of the manner in which the forces were brought to bear to produce this contortion.

As rock beds are rarely horizontal over any considerable area, it is of the utmost importance to understand the effect of faults occurring in inclined beds. If a fault occur in a bed, or set of beds, dipping in a given direction and at a given angle, the vertical throw produces at the surface an apparent shift. Suppose, for example, the bed *a*, in Fig. 20, Plate IV., to dip to the north at an angle of, say, 25°, as indicated in the figure, which is a plan of the outcrop; and a fault *b b* to have occurred, causing a downthrow to the east. In such a case, the outcrop of the beds will be farther south on the east than on the west side of the fault, as shown. To the mining engineer, this circumstance is obviously of great practical importance.

To render the effect of apparent shifts more evident, Jukes, in his 'Manual,' which is the most practical treatise on Geology extant, gives a useful diagram, which we have reproduced in Figs. 21 and 22, Plate IV. If we suppose this to be a section through the bed *a*, in Fig. 20, running north and south in the direction of the fault, we may conceive the part *b* dropped vertically down to *c*, and the part *d*, in the former continuation of the bed, down to *e*. From this position it is clear that a vertical throw of the bed *a a* on one side of the fault will place it as at *a′ a′* on the other side of the fault, and that the respective outcrops of the two pieces of the same bed will, after being worn down to the same level, at the present surface of the ground, which is everywhere a surface of denudation, be at the points *b* and *e*. It is also evident from this diagram that the higher the angle at which the beds dip, the less will be the apparent shift at the surface due to the same amount of throw. In Fig. 22, Plate IV., there is the same amount of throw, that is, the distance *b c* is the same, but the angle having been increased to 60°, the distance *b e* is considerably lessened. Hence it will be seen that when the beds lie at a low angle, a small amount of throw will shift the outcrop to very considerable distances, and that when the beds are vertical, however great that amount may be, it will be almost impossible to detect the fault.

It is obvious from the relations existing between the dip, the throw, and the shift, or "heave," as it is sometimes called, that when any two of these are known, the value of the third may be easily determined. In the practice of surveying, tables are used in which these relations are conveniently expressed, for ready reference. These tables will be described in a subsequent section.

The apparent lateral shift at the surface demands careful attention when occurring in anticlinal and synclinal curves, and an examination of its effects on beds so contorted will clearly show that the positions can be accounted for in no other way but that which we have described, since the apparent shift takes place in opposite directions. If we suppose the Diagram, Fig. 23, Plate IV., to be a sectional plan of a bed in a synclinal, or in an anticlinal, a downthrow on the right, B, of

the fracture in the former case, or a downthrow on the left, A, of the fracture in the latter case, would produce the effects there shown. The example we have given illustrates a simple case; the effect may be complicated by changes in the angle or the direction of the dip, or in the amount of the throw.

The faults we have been considering run at right angles to the strike of the beds. But they may run obliquely to the strike, or even coincide with it. In the latter case, the faults are described as "strike faults." Such faults may entirely conceal some of the beds, and thereby lead to erroneous conclusions as to the succession of the beds. It is possible that strike faults are much more frequent than we suppose, it being exceedingly difficult to detect them where the order of succession has not been established. A simple diagrammatic section of a strike-fault will show how some of the beds become concealed. It is also clear that when the throw diminishes in one direction, the concealed beds will come out to view in that direction.

The number and association of faults also demand consideration. When the fault consists of a single fissure, as the beds must remain joined at the extremities of the fissure, it is evident that displacement can take place only by the beds bending downwards, or sagging, like a rope or a flexible rod placed in a horizontal position. In such a case, the deflection or throw will be greatest in the middle. The character of the beds traversed by the fault may modify this result to some extent, by producing undulations in the downthrow portion. The strain due to the deflection which thus takes place frequently causes the fissure to extend itself at one or both extremities in two or more branches. A fault of this character occurs in the South Staffordshire coal-field, where it is known as the Lanesfield fault.

When the fault consists of two fissures starting from the same point in different directions, the greatest amount of throw will occur at the angle or corner of ground included within the intersection of the two fissures. From this point, to the extremities of the faults, the throw will gradually diminish, as in the preceding case; and the beds will be bent along the line joining those extremities. That there may be no bending of the beds, the fault must consist of at least three straight lines running into each other so as to form a triangle, or of two curved lines running into each other, so as to sever the mass from the surrounding beds. Such faults, if they occur at all, are rare.

Step Faults.—Sometimes a long and powerful fault will consist of a number of parallel fissures at small intervals apart. The total amount of throw may then be divided among the several dislocated portions, so as to form a series of steps, as shown in Fig. 24, Plate IV. It need hardly be stated that the division of the throw among those portions is rarely, if ever, an equal one. In some instances two portions are thrown in opposite directions.

Trough Faults.—Sometimes a junction of faults occurs in such a way as to produce what is called a "trough fault." Such a fault is shown in Fig. 25, Plate V. The opposite faults, the junction of which forms the trough, as $a\,c$, $b\,c$ may be unequal in throw. In this case, the whole mass of the surrounding rock undergoes displacement, as may be seen in the figure, by tracing the beds through their dislocations. When the opposite faults are equal in throw, as $d\,e, f\,e$, only the wedge-shaped mass included between them suffers displacement.

The only satisfactory explanation of the manner in which these faults are formed is that given by Jukes, which is as follows: "Suppose the beds A A, B B, etc., Fig. 26, Plate V., to have been formerly in a state of tension, arising from the bulging tendency of an internal force, and one fissure,

F E, to have been formed below, which on its course to the surface splits into two, E D and E C. If the elevatory force were then continued, the wedge-like piece of rock, W, between those two fissures being unsupported, as the rocks on each side separated, would settle down into the gap, as shown in Fig. 27, Plate V. If the elevatory action were greater near the fissure than farther from it, the single fissure below would have a tendency to gape upwards, and to swallow down the wedge, so that eventually this might settle down and become fixed at a point much below its previous relative position. Considerable friction and destruction of the rocks, so as to cut off the corners, *g h*, would probably take place, and thus widen the gap, and allow the wedge-shaped piece, W, to settle down still farther. When the form of elevation ceased to act, the rocks would have a tendency to sink down again, and resume their original positions. But those newly-included wedge-shaped and other masses would no longer fit into the old spaces, so that great *lateral* compression might then take place."

When occurring in nature, the results described above will be more or less complicated by the irregular action of the elevatory forces, and the heterogeneity of the mass through which the fissures pass; also the lateral pressure alluded to may cause numerous contortions and fractures as the mass settles down. These effects are clearly illustrated by the section, Fig. 28, Plate V., through the Staffordshire thick coal at the commencement of a trough fault. Here a wedge-shaped piece from the rocks above has come down into the coal, and the beds on each side show much crumpling and dislocation as the effects of the consequent lateral pressure. This pressure had reduced the coal on each side of the fault, for a distance of several feet, to a state of powder. Many of the sections of the Geological Survey show similar results in other localities. Fig. 30, Plate VI., shows several examples of faults of dislocation.

Relation between Inclination of Fault and Direction of them.—Though faults are sometimes vertical, as at A B, Fig. 29, Plate V., in the vast majority of cases they are inclined at a greater or less angle. With respect to the direction of the inclination, it has been indisputably established that "no fault traversing any set of beds will make an acute angle with the same bed on both sides of the fault:" that is, a fault such as that represented at E F, in Fig. 29, cannot occur. Hence we have the following invariable rule, the practical importance of which will be obvious.

Rule.—The fault inclines, or "hades," as it is sometimes termed, in the direction of the downthrow.

As a corollary of this rule, it may be stated that whatever the inclination of the fault may be, *no portion of any bed will ever be brought vertically under another portion of the same bed.*

Denudation.—We have already described the effects of currents of water in removing portions of beds, as results of erosion. When, however, the same effects are produced upon a large scale, it is customary to speak of them as the result of denudation. As all the aqueous rocks have been formed from the detritus of other rocks, it is evident that denudation must be co-extensive with deposition. A vivid realization of its nature and its effects is of essential importance to the student of Geology; for apart from the production of sediment, and ultimately of sedimentary rocks, it has acted more than any other cause in fashioning the external contour of the dry land. It is easy to prove that the present surface has been produced by the removal of a great thickness of solid rock. The proof may be found in the geological structure of a district. Take, for example, the frequent case of an escarpment and an outlier, such as that shown in Fig. 31, Plate VI. The beds ending in the escarpment X, were evidently once continuous to the outlier Z, and beyond Z. The excavation of the valley Y,

and the formation of the low country beyond Z, thus isolating the hill Z, are the effects of denudation. If the whole of the escarpment X and the outlying hill Z had been removed so as to form a level surface, the character of the agency that produced it would be equally apparent in the fact that the surface was formed by the outcrop of the strata. Such surfaces are numerous, and indicate the removal of an enormous quantity of rock. The actual depth removed cannot be ascertained, but in some instances a minimum depth may be assigned. In the antilinal A, Fig. 8, Plate II., the dotted lines represent the portions of the beds 5, 6, 7, and 8, that have been removed to form the present surface. If the total thickness of those beds at their outcrop be 1000 feet, it is clear that that depth must have originally existed above bed 4, the present surface of the ground. But the total depth removed was even greater than this, because there are beds cropping out beyond No. 8, which must have been covered by them. Another striking indication of the vast effects of denudation is furnished by the fact that, in most cases, the irregularities occasioned by faults have been wholly removed from the surface. When it is borne in mind that faults are by no means rare in which the strata have been elevated or depressed to the extent of 500 or 600 feet, the magnitude of the powers that have planed down such precipices will be apparent.

To the mining engineer, the action and the effects of denudation are of the highest importance. In numerous instances, immense sums of money have been expended in sinking shafts for coal in places from which the coal measures have been removed—a circumstance that a little knowledge of geology would have rendered evident.

Other examples of the effects of denudation are given in Figs. 32 and 33, Plate VI. The former is a diagrammatic section through a portion of the Cleveland districts, surveyed by the writer for ironstone. On the right of the figure, at A, the series consist, in the ascending order, of the lower and middle lias, a seam of ironstone, I, the upper lias, consisting of the jet and alum shales, and a sandstone capping, representing the lower oolite. At B, the sandstone bed and a portion of the shales have been removed. At C, the denuded portions reappear; but beyond this, at D, the whole series down to the lower lias has been carried away. From this example, as well as from Fig. 31, it will be seen how denudation operates to form hills.

In Fig. 33, Plate VI., we have a section of the county through Trentham Park, in North Staffordshire, as given by Mr. E. Hull, of the Geological Survey. The beds of quartzose conglomerate which come to the surface at A, have undergone denudation. At A′, a downthrow again brings them in; the upper portions of the anticlinal having been worn away, the beds reappear at A″, where an upthrow separates them from their continuation at A‴.

Unconformity.—The deposition of rock beds takes place, as we have shown, in parallel layers. This parallelism is not destroyed by any subsequent tilting that may occur. Beds so placed with respect to each other are said to be "conformable," or to lie conformably over each other. When, however, denudation and subsequent deposition take place, it is easy to see that this conformity may not exist. If, for example, the escarpment and outlier, in Fig. 31, Plate VI., were removed, and another set of beds deposited over the surface, these would lie unconformably upon those forming the surface of denudation. Hence it will be seen that unconformity is a consequence of denudation, and is of great practical importance, for it is from it that we derive some of our clearest and most vivid notions of what may be effected in the process of denudation. An example of unconformity is given in Fig. 34, Plate VI., where beds of conglomerate of the new red sandstone rest upon beds of the permian sandstone.

"Overlap" is a term used to express the greater extension or spread of any set of superior strata by which they overlap and conceal the edges of those beneath them. In some instances, an overlap has been mistaken for unconformity, though the two are very different phenomena.

Chronological Order of Formation.—Hitherto we have been considering rock beds in their lithological and petrological relations. It now remains to view them as members of a chronological series. It is obvious, from the mode of formation of rock beds, that any given bed is of more recent origin than that upon which it rests, and of more remote origin than that which lies immediately above it. This fact furnishes us with the means of ascertaining the relative age of any bed or set of beds. But it is equally obvious, from what we have seen of the effects of disturbing forces and denuding agents, that beds which, in one place, are covered by a vast thickness of other beds, in another place may form the present surface of the ground. Hence it by no means follows that beds which lie nearest the surface are of the most recent formation. Extended observation has, however, established these most important facts, namely, that in some places there exist beds which are nowhere overlaid by others; that the beds lying immediately beneath these are nowhere else overlaid by others; that the next again in succession are nowhere overlaid by any but one or the other, or by both, of the two former; and so on down through the whole series of sedimentary rocks. From this we learn that there exists an invariable order of succession. This order is called the *Order of Superposition*, and by it we are enabled to determine the relative age of any bed or set of beds. The practical importance of being able to correctly assign to any set of beds its chronological position in the series is very great. To take a simple example: Suppose we find a surface formed of the old red sandstone. It would evidently be futile to sink for coal in that locality, because the carboniferous beds are of more recent formation than the former, and would, therefore, not exist beneath them. Or, again, if we are sinking through beds which in geological order lie above the coal measures, and come unexpectedly upon the old red sandstone, we know that the coal measures were either never deposited in that place, or that they have been removed by denudation, and that, consequently, it would be a sheer waste of money to continue the sinking deeper.

Having established an order of superposition, it becomes necessary to divide the series of beds in some manner convenient for reference; and to do this, we very properly look for some natural divisions. We find, for example, a set of rock beds called the "millstone grit," and we speak of the time during which these beds were deposited as the millstone grit age. But the millstone grit occurs among a group of beds remarkable for the carbon which they contain, either as a constituent part, or as interstratified deposits. And in speaking of the time during which this group was deposited, we designate it as the Carbon Period. Again, it has been remarked that the fossil remains indicate a natural division. From the most recent deposits, down to a certain point, the remains are those of species still existing, or of species closely allied to existing species. From this point down to another point, the remains are those of species differing essentially from those now existing; and from the latter point down to the fundamental granite, the species are again different till they disappear altogether. It must not, however, be supposed that these points are distinctly defined. On the contrary, the species die out gradually. But though somewhat arbitrarily fixed, they are sufficiently well defined for practical purposes. These distinctions divide the whole series of sedimentary rocks into three epochs, called the Primary or Palæozoic (*ancient life*), the Secondary or Mesozoic (*middle life*), and the Tertiary or Cainozoic (*recent life*). It is necessary, to clearness of understanding, that the distinction here pointed out between the expressions "age," "period," and

"epoch," should be constantly observed in all geological considerations. Unfortunately, writers on Geology frequently employ them indiscriminately.

It must be borne in mind that the names given to a set of beds, as the "chalk," the "Kimmeridge clay," the "old red sandstone," etc., though in themselves indicative of lithological character, locality, or some other attribute of some particular variety of rock, are used solely with reference to time. That is, by the expression the "chalk," we mean not only the chalk itself, but all beds of the chalk age. These may consist of black marble, brown sandstones, or blue slate. In the same way, the old red sandstone may be sandstone in one place, and clay-slate in another; and Kimmeridge clay may be found at places far remote from the locality whence it takes its name.

The divisions of geological time are as follows:

I.—Primary, or Palæozoic Epoch.	II.—Secondary, or Mesozoic Epoch.	III.—Tertiary, or Cainozoic Epoch.
1. The Laurentian Period. 2. The Cambrian Period. 3. The Silurian Period. 4. The Devonian, or Old Red Sandstone Period. 5. The Carbon Period. 6. The Permian Period.	1. The Triassic Period. 2. The Jurassic, or Oolitic Period. 3. The Cretaceous Period.	1. The Eocene Period. 2. The Miocene Period. 3. The Pliocene Period. 4. The Recent Period.

TABLE OF SEDIMENTARY STRATA.

Tertiary, or Cainozoic Epoch.	Pliocene Period—Crag ..			Norwich Crag. Suffolk Crag.	
	Miocene Period			Leaf Bed of Mull. Lignite of Antrim. Bovey Beds with Lignite.	
	Eocene Period.	Upper.	Hempstead Beds.	Corbula Beds.	
				Upper Middle Lower	Fresh-water and Estuary Marls.
			Bembridge Beds.	Bembridge Marls. „ Limestone.	
			Osborne Beds.	St. Helen's Sands. Nettlestone Grits.	
		Middle.	Headon Beds.	Upper Middle Lower	Headon Beds.
			Bagshot Beds.	Upper Bagshot Sand.	
				Middle „	Barton Clay. Bracklesham Beds.
				Lower „	Sand and Pipeclay.
		Lower.	London Tertiaries.	London Clay and Bognor Beds.	
				Oldhaven Beds Woolwich and Reading Beds Thanet Beds	Plastic Clay.

Secondary, or Mesozoic Epoch.	Cretaceous Period.	Upper.	Chalk.		Upper Chalk, with layers of Flint.
					Lower Chalk, without Flints.
					Chalk Marl.
					Chloritic Marl.
			.. ..		Upper Greensand, Malm Rock, etc.
		Lower, or Neocomian.	.. ..		Gault Clay.
			Lower Greensand.		Folkestone Beds.
					Sandgate Beds.
					Hythe Beds.
					Atherfield Clay; Speeton Clay.
			Wealden.		Weald Clay.
				Hastings Sand.	Upper Tunbridge Wells Sand.
					Grinstead Clay.
					Lower Tunbridge Wells Sand.
					Wadhurst Clay.
					Ashdown Sands.
					Ashburnham Beds.
	Oolitic Period.	Upper.	Purbeck.	Upper Middle Lower	Purbeck Beds.
			Portland.		Portland Stone.
					Portland Sand.
					Kimmeridge Clay.
		Middle.	Coralline Oolite.		Upper Calcareous Grit.
					Coral Rag.
					Lower Calcareous Grit.
			Oxford Clay.		Oxford Clay, and
					Kellaways Rock.
		Lower.	Forest Marble.		Cornbrash.
					Forest Marble, and
					Bradford Clay.
			Great Oolite.		Great, or Bath, Oolite.
					Stonesfield Slate.
					Northampton Sand.
			Fullers' Earth.		Upper Fullers' Earth (Clay).
					Fullers' Earth Rock (Limestone).
					Lower Fullers' Earth (Clay).
			Inferior Oolite.	Chelten-ham.	Ragstone and Clypeous Beds.
					Upper Freestone.
					Oolite Marl.
					Lower Freestone.
					Pea Grit.
					Collyweston Slate, Lincolnshire.
					Sands.
		Lias.	Upper Lias.		Clay and Shale.
			Middle Lias.		Marlstone.
			Lower Lias.		Clay, Shale, Limestone, and Bone Beds.

NORTH AMERICA.

(The Carboniferous Beds of the United States, as grouped by Professor Rogers, are as follows: *Upper Group.*—Alternations of greyish and reddish sandstones, shales, and coals, thinning out westward. *Middle Group.* —In Pennsylvania, soft red shales, and argillaceous red sandstones. In Virginia, blue, olive, and red calcareous shales, with thick red and brown sandstone; light-blue limestones; and buff, greenish, and red shales. In the Western States, grey and yellow sandstones, and light-blue and yellow sandstones. *Lower Group.*—White, grey, and yellow sandstones, alternating with coarse siliceous conglomerates, and dark-blue and olive-coloured slates. In some places black carbonaceous slate, and a few beds of coal.)

	Triassic, or New Red Sandstone Period.	Upper Triassic.		Keuper.	Red Variegated Marl, and Upper Keuper Sandstone. Lower Keuper Sandstone and Marl. (Water Stones.) *Muschelkalk, absent in Britain.*	
		Middle Triassic.		.. ..	Dolomitic conglomerate.	
		Lower Triassic.		Bunter.	Upper Red and Mottled Sandstone. Pebble Beds, Calcareous Conglomerate, and Breccia. Lower Red and Mottled Sandstone.	
Primary, or Palæozoic Epoch.	Upper Palæozoic.	Permian Period.		Upper, or Magnesian Limestone.	Red Marl. Magnesian Limestone. Marl Slate.	
				Lower.	Lower Red Sandstone.	
		Carbon Period.		Coal Measures.	Upper Coal Measures. Middle Coal Measures. } Pennant Grit. } Lower Coal Measures. Gannister Beds.	NOVA SCOTIAN SYSTEM. Upper Group. — Greyish and reddish sandstones and shales, beds of conglomerate, and thin beds of limestone and coal.
				.. ..	Millstone Grit, or Farewell Rock.	Middle, or Good Coal Group. — Grey and dark-coloured sandstones and shales, with red and brown beds of same; coal, ironstone, and bituminous limestone.
				Carboniferous, or Mountain Limestone.	Upper Limestone Shale (Yoredale Rocks). Carboniferous Limestone. Lower Limestone Shale.	Lower, or Gypiferous Group. — Red and grey sandstones and conglomerates, and red and green marls, with thick beds of gypsum and limestone.
		Devonian and Old Red Sandstone Period.		Devonian Beds.	Upper Devonian, or Barnstaple and Marwood Beds, with Petherwin Limestone in N.E. Cornwall. Middle Devonian, or Ilfracombe Beds, with Fossiliferous Limestones and Cornstones. Lower Devonian, or Lynton Beds.	Upper Helderberg Group. Upper. — Catskill Group, or Old Red Sandstone. Middle. — Chemung Group. Portage Beds. Genoese Slate. Tully Limestone. Hamilton, or Moscow Shale. Marcellus Shale. Lower. — Corniferous Limestone. Onondago Limestone. Schoharrie Grit. Caudigalli Grit. Oriskany Sandstone.
	Lower Palæozoic.	Silurian Period.	Upper.	.. ..	Tilestones or Passage Beds.	
				Ludlow Beds.	Upper Ludlow Beds (with Bone Bed). Aymestry Limestone. Lower Ludlow Beds.	Lower Helderberg Group.
				Wenlock Beds.	Wenlock Limestone. Wenlock Shale, Sandstone, and Flags. Woolhope Limestone and Shale, and Denbighshire Grits, Shales, Slates, and Flags.	Onondago Group.
				Llandovery Beds.	Upper Llandovery Rocks. Lower Llandovery Rocks.	Clinton Group. Medina Sandstones. Oneida Conglomerate.

Lower Palæozoic.	Lower.	Caradoc, or Bala Beds.	Caradoc and Bala Beds. Sandstone (often Shelly) with Bala Limestone, Shale, and Slate.	Hudson River Beds. Utica Slate. Trenton and Birdseye Limestones.
		Llandeilo.	Upper Llandeilo Flags, and Limestone, &c. Tremadoc Slates.	Quebec Group (Limestones). Calciferous Sandstones.
		Lingula Beds.	Lingula Flags.	Potsdam Sandstones. St. John's Group.
	Cambrian Period.	Cambrian.	Harlech Grits, &c. Purple Slates and Grits (St. David's). Llanberis Grits and Slates. Longmynd Rocks. Red Sandstone and Conglomerate (Scotland).	Huronian Beds of Canada.
	Laurentian Period.		Fundamental Gneiss of the N.W. Scotland, &c.	The Lower and Upper Laurentian Gneiss of Canada.

The Laurentian Period.—The rocks of this period consist of ancient sedimentary strata which have become highly crystalline. They are very largely developed along the country drained by the St. Lawrence, in Canada, whence the name has been derived. The rocks of this formation are the most ancient yet known. The only parallel existing in Great Britain is the gneiss of the north-west of Scotland.

The Cambrian Period.—Next to the Laurentian in ascending order is the Cambrian Period, the rocks of which are largely developed in Wales, whence the name. They consist of schists, grits, and crystalline limestone, and have undergone a less degree of metamorphosis than the Laurentian series. These rocks may be seen largely exposed in the hilly ground between Harlech and Dolgelli, in parts of Caernarvonshire west of Snowdon, and in the Longmynd, a range of hills on the north-west of Church Stretton, in Shropshire, where they show a thickness of 23,000 feet. The Penrhyn and Llanberis slate quarries are in a band of slate in the upper part of this series. In Scotland, the rocks which may be assigned to this period are the red and purple sandstones and conglomerates which lie to the south of Cape Wrath, upon the gneiss, where they attain a thickness of 8000 feet. In Ireland, large masses of rock, consisting of dull green, brown, purple, and liver-coloured slates, like those of North Wales, existing in the mountain district of South Wexford, the northern portion of County Wicklow, and in the hill Howth, in County Dublin, have been assigned to this period.

In Canada, the Laurentian gneiss is covered unconformably by a series of sandstones of great thickness, known as the "Huronian" beds.

The physical aspects characteristic of Laurentian and Cambrian districts are bold, rugged hills and mountain ranges, abounding in steep precipices and splintery peaks; deep and narrow gorges, and outlines marked by that irregularity which is always possessed by slaty formations when deeply weathered.

The Silurian Period.—The term Silurian has been applied to an important series of rocks first surveyed by Sir R. Murchison in the eastern portion of Wales, formerly inhabited by a tribe named the Silures. These rocks consist of dark-coloured laminated shales, frequently with limestone concretions, calcareous flagstones, thick-bedded sandstones, and pebbly conglomerates, finely laminated micaceous sandstones, shales, and impure clayey limestones, and limestones of a con-

cretionary structure. They have been divided into upper and lower groups, a division which holds good wherever silurian rocks have been discovered.

The *Lingula flags* lie immediately above the Cambrian rocks, westward of the Longmynd, in Shropshire, and also notably in Caernarvonshire, between the Menai Straits and the crest of the Snowdon range. They consist of masses of dark slate, often ferruginous, with banded arenaceous flags, the surfaces of which are spotted with impressions of *lingulæ*. The *Llandeilo flags* consist of beds of dark slate and sandy flags, with occasional bands of sandstone. The series is more fully developed in North Wales, but the beds may be well seen near Llandeilo Favor, in South Wales, whence the name is derived. The *Caradoc and Bala beds* consist, the former of brown sandstone, with occasional calcareous bands, the latter of grey grits and slates, much invaded by igneous rock. They are most fully developed near the town of Bala, in Merioneth. The *Lower Llandovery beds* consist of shales, sandstones, and conglomerates. They come in over the Bala beds, near the town of Llandovery, whence they run in a southerly direction. At the same place, the *Upper Llandovery beds* come in. These are similar to the lower beds in lithological character, but they are distinct from the latter in lying unconformably upon and overlapping them. This unconformity is everywhere existent between the upper and lower silurian rocks. The upper Llandovery beds usually consist of grey, brown, or yellow sandstones, sometimes passing into a conglomerate. The sandstones are in some places calcareous. The *Wenlock beds* consist, near Llandovery, on the west of the Malvern Hills, at Great Barr, in Staffordshire, and at May Hill, of grey argillaceous concretionary limestone, interstratified with grey shales. In North Wales they are composed of coarse brown sandstone, with occasional quartzose conglomerates, and interstratified with black slates, passing up into brown flags. These are known as the *Denbighshire grits, slates, and slabs.* The *Wenlock limestone* consists of an irregularly occurring set of concretionary limestones, which are sometimes thin and flaggy, and sometimes form massive bosses of highly crystalline carbonate of lime. These beds, which are sometimes interstratified with shales, exist between Aymestry and Ludlow, along Wenlock Edge to Bethnal Edge, near Coalbrookdale, at the Castle Hill, and Wren's Nest, near Dudley, near Walsall, and in the neighbourhood of Usk.

The *Lower Ludlow beds* are similar in character to the Wenlock shales, consisting of soft dark sandy shales, with spheroidal calcareous concretions. Locally they are known as "mudstones." The *Aymestry limestone* is a dark grey limestone, less pure than the Wenlock limestone. The latter is called by the workmen of South Staffordshire "the white limestone," and the former "the black limestone." The *Upper Ludlow beds* consist of slightly micaceous sandy shale or flag, or soft argillaceous sandstone, closely resembling the lower beds, of a bluish-grey colour, but weathering rusty brown or greenish-grey. They pass upwards by insensible gradations into red sandy flags, locally known as "tilestones."

Scotland.—The localities in Scotland where silurian rocks occur are the southern uplands, which are formed almost wholly of rocks of the Lower Silurian Period, probably of the Llandeilo age; and the neighbourhood of Kirkudbright, the Pentland Hills, and the valley of the Girvan, Ayrshire, where representatives of the upper group exist.

Ireland.—In Ireland, lower silurian rocks are found in Wicklow, Wexford, and Waterford, and in the island of Lambay, and the promontory of Portraine, in County Dublin. Representatives of the upper group are found in Galway, near Maam, and at the south-west end of Lough Mask;

at Ughool, near Ballaghadereen, Lisbellaw, south of Enniskillen, in the Cratloe Hills of Limerick, and in the Dingle Promontory, in County Kerry.

THE DEVONIAN AND OLD RED SANDSTONE PERIOD.—Lying immediately above the silurian rocks is a set of beds to which, on account of their large development in the county of Devon, the name of "Devonian" has been given. These beds, which consist mainly of schists and limestones, have been divided into the lower, middle, and upper. The lower, or *Lynton beds*, consist of red sandstones and conglomerates resting upon the shales and slates. The middle, or *Ilfracombe beds*, are formed of grey schists and limestones; and the upper, or *Barnstaple and Marwood beds*, are made up of slates, shales, and calcareous bands. In South Devon these beds produce coarse roofing slates, and in many places consist of red and variegated sandstones and flagstones. The whole have been greatly disturbed and contorted.

Belonging to the same period, but differing widely in lithological character from the Devonian rocks, there exists, in the district which gave its name to the silurian formation, a set of beds of great thickness. These beds are composed mainly of red sandstones. In some places conglomerates, limestones, and clays occur, and in others the sandstones may be purple, green, yellow, or even white; but the prevailing characteristic of the beds is red sandstone. The name of Red Sandstone has, therefore, not inappropriately been applied to this formation; and to distinguish it from another formation of red sandstone occurring above the coal measures, it is called the Old Red Sandstone. In Shropshire, the old red sandstone beds rest upon the upper Ludlow rocks, and they contain occasional beds of conglomerate, red and green clays, and marls, with bands of impure arenaceous limestones, locally known as "cornstones." The beds dip gently to the south-east, beneath the Clee Hills, whence they spread to the south-west, through Hereford into Monmouth and Brecknock, attaining here a vast thickness, and thence into Caermarthenshire, where they are tilted up into the vertical position.

Scotland.—The old red sandstone rocks are best developed in Scotland, where they may be divided into three groups: the lower, the middle, and the upper. Besides these divisions, they may be regarded as occurring in two types, one existing on the north, the other on the south, of the Grampian range. The latter is distinguished by an abundance of interbedded volcanic rock, and a poverty of organic remains; the former by the absence of the igneous rock, and a comparative abundance of fossils.

In the southern type, the lower group consists of red, chocolate-coloured, and grey sandstones and shales, with great masses of volcanic rock, and occurs largely in the Sidlaw and Ochil Hills, the Pentland Hills, and the country stretching thence into Ayrshire. The middle group is composed of reddish, green, and grey sandstones, flagstones, and conglomerates, with an abundance of volcanic rock, and may be seen in the south-west of Ayrshire. The upper group consists of red and yellow sandstones and conglomerates, and is found in Berwickshire, Haddingtonshire, and Fife. Of these three groups, the lower, as developed in Edinburghshire and Lanarkshire, rests conformably upon the upper silurian; the upper lies conformably against the carboniferous formation, and the middle is separated from the other two by an unconformity. In the northern type the unconformity does not exist. The lower group consists of red sandstones and conglomerates, resting unconformably upon the metamorphic rocks of the Highlands. The middle group consists of grey and dark flagstones, sometimes calcareous or bituminous, and covers a large area in Caithness, and extending thence to the Orkney Islands. The upper group is composed

of light red and yellow sandstones, and occurs largely at Dunnet Head, and in the Orkney and Shetland Islands.

Ireland.—In Ireland two groups of old red sandstone exist, separated from each other by an unconformity. The lower group is found in County Kerry, and is known as the *Dingle beds.* These consist of red and green grits, and purple slates, with bands of purple conglomerate. The upper group, consisting of red sandstones and conglomerates, comes in unconformably over these as the peninsula expands. The old red sandstone beds of Kilkenny, Waterford, and Cork, composed of red sandstones and slates, rest unconformably upon the lower silurian rocks.

The physical aspects of old red sandstone districts are highly diversified and irregular. The hills are less bold and precipitous than those of older districts, but more lofty and irregular than those of the later secondary formations.

THE CARBON PERIOD.— Immediately above the Devonian and old red sandstone formation occurs a set of beds which, from the large amount of carbon derived from vegetable matter which they contain, have been named the carboniferous series. As it is from these beds that coal is obtained, they constitute the most important of the sedimentary rocks.

The Lower Limestone Shale consists of dark earthy shales, sometimes interstratified, in its lower portion, with yellowish sandstones, and always terminating upwards in thin flaggy limestone, thus graduating downwards into the old red sandstone, and upwards into the carboniferous limestone. In some districts it is very scantily developed; in others it attains a great thickness.

The Carboniferous or Mountain Limestone.—The carboniferous limestone constitutes the most distinct and remarkable set of beds of the Carbon, and, indeed, of any Period. So marked are its characteristics, that it becomes a kind of guide-post both to the miner and to the geologist. It occurs as a compact rock, usually of a dark grey, but sometimes of a reddish colour. In some localities it becomes bituminous, forming the statuary "black marble;" in others it forms the "stinkstone" and "rottenstone," already described. In certain localities, as in Derbyshire, for example, the bitumen exists in the joints and fissures in a free state, especially in the neighbourhood of trap dykes, constituting petroleum springs. The name of "Mountain Limestone" has been applied to these beds, because they are very generally found capping the trap hills that intervene between the old red sandstone and the carbon formations. This limestone occurs sometimes in one thick bed several hundred feet thick, separated by a few partings of calcareous shale; sometimes, as near Bristol, interstratified with brown, grey, and red shales in the lower, and with shales and sandstones in the upper portion. It everywhere contains remarkably characteristic fossils.

The carboniferous limestone is absent from the coal-fields of the midland counties; the coal measures there resting upon Cambrian or silurian rocks.

The Upper Limestone Shale and Yoredale Rocks.—Above the carboniferous limestone lies a group of shales, with thin, black earthy limestones at the bottom, and thin, fine-grained sandstones at the top, known as the "Upper Limestone Shale." In some districts, but more especially in Yorkshire, this group becomes confused with the limestone beneath, and the millstone grit above; the upper portion of the former being split up into beds of shale and thin limestones, and the lower portion of the latter into shales and thin sandstones. To the group thus constituted, the name of "Yoredale Rocks" has been applied; and the limestone beneath, in the district whence this name was derived, is known as the "Great," or "Scaur Limestone."

The Millstone Grit, or Farewell Rock.—The Millstone Grit consists of a series of hard, coarse-grained, quartzose sandstones, usually of a grey, white, or yellow colour, but sometimes reddish, as near Bristol. Locally, and among miners, the millstone grit is known as the "rough rock." It is not a persistent group, but it is largely developed, and consequently occupies an important place in the carbon formation, in some districts, as in the South Wales, Bristol, Lancashire, and Yorkshire coal-fields. Its maximum thickness may reach 1000 feet. It is often interstratified with shales, and occasional thin seams of coal.

The Gannister Beds.—The beds known as the "Gannister" are composed of hard, micaceous sandstones, interstratified with shales, and in some places thin seams of coal. They are developed in the Derbyshire, Lancashire, and North of England coal-fields.

The Coal Measures.—The Coal Measures consist of an enormous series of alternations of beds of sandstones, shales, and coal, with occasional bands of ironstone. There does not appear to be any marked order or succession among these beds; but generally gritty sandstones prevail towards the base, and sandstones and marly shales towards the top of the series. The coal seams vary in thickness from one inch to many feet. In the Bristol coal-fields the measures have a central band of hard sandstones, called the Pennant rock, which divides them into three sub-groups: the lower, the middle or Pennant, and the upper. The sub-divisions here naturally existing have been artificially retained for the sake of convenient reference in other districts. The middle measures generally contain the chief seams of coal, those of the lower and upper being thinner, and of inferior quality. The carboniferous formation is magnificently developed in England, attaining in the Lancashire district the enormous thickness of 18,000 feet. A detailed description of the formation as it exists in the several districts will be found in the last chapter of this work.

Scotland.—The beds of the Carbon Period are well developed along the great midland valley of Scotland, stretching from the Firth of Clyde to the Firth of Forth. The conditions which gave rise to the Yoredale rocks appear to have operated more strongly as we go northward, so that the massive limestone base has given place to alternating beds of sandstones and shales, interstratified with comparatively few thin limestone bands. The formation, as determined by the Geological Survey, consists of the "calciferous sandstones," the "carboniferous limestones," the "Moor Rock"—the representative of the millstone grit,—and the "coal measures." The *calciferous sandstones* consist of two groups: the lower and the upper. The former is composed of purple, red, and reddish-grey sandstones, sandy shales, and conglomerates, with occasional bands of cornstone. These generally rest unconformably upon the old red sandstone and silurian formations. The latter group is composed of white and grey sandstones, blue and black shales, often highly bituminous, limestones, cornstones, and occasional seams of coal. This group is less persistent than the lower, thinning out and disappearing altogether in some places. The *Carboniferous Limestones* consist of sandstones, shales, coals, ironstones, and bands of limestones; the coal-bearing beds occupying the middle of the series. In the Linlithgowshire and Fife districts, volcanic rock is abundantly intermingled with the carboniferous limestone. The *Moor Rock* consists of coarse white and grey sandstones and grits, with some thin coal seams. These beds are largely developed in Edinburghshire, Fife, and Lanarkshire, but die away so as to become indistinguishable in Ayrshire. The *Coal Measures* may be divided into two groups: the lower, consisting of white and grey sandstones, shales, coals and ironstones; and the upper, made up of red sandstones and clays.

Ireland.—In Ireland, the lower beds of the Coal Period are very fully developed. In the

south, a set of beds composed of grey and greenish-grey grits, with interstratified black and grey slates (the coomhola grits), and a succession of black and grey slates intervene between the old red sandstone and the carboniferous limestone. The latter is magnificently developed. In the north a set of shales and sandstones, called the "Calp," exists in its middle portion. Only the lower members of the coal measures are found, the superior beds having been removed by denudation. These members represent a portion of the millstone grit and Yoredale beds of England. They consist of black shales, with occasional bands of thin grit, grey sandy flags, with black shales; and black shales and grey grits, containing thin seams of coal.

The physical aspect of carbon districts is generally flat, or gently undulating, and hence the scenery is unpicturesque. And the soil, being derived from the clays, is usually retentive of moisture, and cold.

The Permian Period.—Immediately above the coal measures occurs a set of beds consisting of red sandstones and marls, similar in general aspect to the old red sandstone, magnesian limestones, and red shales. To these beds the name of Permian has been given, from the government of Perm, in Russia, where they are very fully developed. The series has been divided into two portions, known respectively as the "Lower" and the "Upper Permians."

The Lower Permians consist of the *Lower Red Sandstones and Marls*. They form an irregular deposit, and are found lying unconformably upon the coal measures, and in hollows eroded in their surface. They contain fossil plants of the same species as the coal measures. The prevailing colour of these beds is a deep red, but in some localities they are purple or yellow. The *Marl Slate*, the lowest member of the Upper Permians, is a reddish or brown indurated fissile shale, with occasional thin beds of compact limestone. The *Magnesian Limestone* is an extensive deposit, remarkable for its singular and diversified structure. In some places it occurs compact; in others, crystalline, brecciated, oolitic, cellular, and earthy. The concretions are often very remarkable; sometimes appearing like piles of cannon or musket balls, sometimes like bunches of grapes. In hardness the magnesian limestone varies from the very hard to the easily friable. Its prevailing colour is a light yellow or fawn colour; but occasionally it is red or brown. When of granular and crystalline texture, it is known as "Dolomite." The *Red Marl* consists of red and mottled marls, gypseous and saliferous, in some places interstratified with thin beds of limestone. The name of marl has been applied to the shale deposits of this period, rather on account of their occurring in a mottled, friable, and non-laminated state, than because they contain any notable quantity of lime.

The permian beds as described occur in the north-east of England. In the north-west they consist of the lower red sandstone, red marls, with thin beds of magnesian limestones, and the upper, or St. Bees, sandstone. In the midland counties the limestones die away towards the south, and disappear near Nottingham. There is, however, in Warwickshire, Staffordshire, and Shropshire, a set of beds composed of red marls and sandstones, with thick bands of cornstones and trappoid breccia, which occupy the same relative position as the permian beds.

Scotland.—There is in Scotland several detached areas of red sandstones that have been referred to this period, notably those of Dumfriesshire and Ayrshire.

Ireland.—Red sandstones of the Permian Period are found at Rhone Hill, near Dungannon, in Tyrone; and yellow magnesian limestones occur at Ardtrea, Tyrone.

The Triassic, or New Red Sandstone Period.—Overlying the permian beds, and consisting mainly of red sandstones and marls of a similar character, occur the beds known as the *Trias*, or

New Red Sandstone. The term "trias" was applied to this formation by German geologists, because on the Continent it consists of three distinct portions: *Bunter*, or variegated sandstones; *Muschelkalk*, or shelly limestones; and *Keuper*, or variegated marls. The "Muschelkalk" is wanting in England; but the "Bunter" and "Keuper" series are largely and distinctly developed. In the place of the Muschelkalk, however, some geologists put the *Dolomitic conglomerate* of Somerset, Gloucester, and South Wales.

The Bunter series consist, in the lower portion, of soft red and mottled sandstones; in the middle portion, of pebble beds, or uncompacted conglomerates; and in the upper portion, of soft red and mottled sandstones. The Keuper series are composed, in the lower portion, of brown, yellow, and white sandstones, with thin laminated sandstones and marls, called "water stones," and in the upper portion, of red and mottled marls, with rock salt and gypsum.

A remarkable and very important feature of the new red sandstone, or "Red Rock," is that it rests unconformably and indiscriminately upon any or all of the formations already described. Previous to the deposition of these beds, the palæozoic rocks had undergone great distortion and enormous denudation. Upon the irregular surface thus produced, the new red sandstone was deposited in a horizontal or nearly horizontal position; and hence the beds become thick, sometimes suddenly, where former hollows existed; thin where the older rocks rise to near the present surface of the ground, and end against these older rocks when they rise into hills, around the margins of which they sweep with a flat or gently undulating surface. In this way, the new red sandstone surrounds the Pennine chain of the north of England, from Lancashire, through Cheshire into Shropshire, Staffordshire, Leicestershire, and Nottinghamshire, and runs down the vale of York to the coasts of Durham. In the same way, it bounds the palæozoic rocks of Wales from the mouth of the Dee to the mouth of the Severn, and continues thence through Somerset and Devon to the mouth of the Exe. Dr. Buckland, in his 'Bridgewater Treatise,' remarks that if we draw a slightly sinuous line from the mouth of the Tees to the mouth of the Exe, we should divide England into two totally dissimilar parts. The part to the north-west of such a line is chiefly palæozoic ground, wild, barren, and mountainous, but full of mineral wealth. The part to the south-east is secondary and tertiary ground, generally soft and gentle in outline, but containing no wealth beneath the soil.

The practical importance of the irregularity of the new red sandstone beds will be seen in the facts that when the thickness of the beds has been determined at one point, the thickness at another point only a few hundred yards distant, may be enormously increased or diminished, and that when the beds have been pierced, any one of the older formations may be met with.

Scotland.—No definitely marked representatives of the trias have yet been discovered in Scotland.

Ireland.—In Ireland, the new red sandstone formation is confined to County Antrim and its immediate borders, where it is largely developed.

The physical aspect of triassic districts is flat and generally uninteresting. Though covering a vast extent of country, it nowhere rises to a greater height than 800 feet.

The Jurassic or Oolite Period.—Overlying the trias, occurs a set of beds differing in a marked degree from those beneath them. As these beds are largely developed in the Jura Mountains, they have been called *Jurassic* on the Continent; but in England they are more commonly known as *Oolite*, on account of the presence in them of oolitic limestone. The lower portion of this formation is occupied by an important series of beds called the *Lias*, a corruption of *liers* or *layers*, a name having

reference to the thin beds of limestone that occur among them. "The peculiar aspect," says Sir C. Lyell, "which is most characteristic of the lias in England, France, and Germany, is an alternation of thin beds of blue or grey limestone, with a light-brown weathered surface, separated by dark-coloured argillaceous partings, so that the quarries of this rock assume, at a distance, a striped and ribbon-like appearance." The clays, however, generally predominate, the series being essentially a great clay deposit. The clays or shales are mostly bituminous and pyritous, and it is no uncommon thing for the Yorkshire lias cliffs to ignite spontaneously, after wet weather, and to burn for several months.

The Lias.—At the base of the lias, in the south-west of England, occurs a set of beds sometimes included with the lias, but more frequently referred to as the Rhætic, Penarth, or Passage beds. They consist of white or cream-coloured, and more or less argillaceous limestones, largely developed in Somersetshire, and known as "white lias;" occasional layers of a greenish siliceous limestone, with iron pyrites, and numerous scales, teeth, and bones of fish and saurians, and hence called bone beds; and alternations of hard and soft grey or greenish marls, passing imperceptibly down into the red marls of the Keuper.

The *Lower Lias* consists mainly of alternating bands of bluish grey argillaceous limestones, and laminated clay or shale. In some parts, as in the west of England where the lias has been deposited upon the Palæozoic rocks, the clays and shales are absent, and the limestones become more close-grained and harder. The *Marlstone* constitutes a well-marked division of the lias; it is more arenaceous than the rest of the series, and in parts very calcareous and ferruginous. Frequently workable bands of ironstone occur in the marlstone; the vast iron deposits of the Cleveland district are in this portion of the lias. The *Upper Lias* is composed of blue clay and shale, graduating up into the inferior oolite above. In some districts, as in North Yorkshire, these shales contain jet and alum. As developed in England, the lias occupies a belt of varying breadth, extending from Lyme Regis, in Dorset, northwards by Bath, Gloucester, Leicester, Newark, and Gainsborough, to the Humber, and thence to the east coast of Yorkshire.

The Oolite Series.—Resting upon the lias, the oolitic beds occupy in England a broad parallel belt stretching from Dorset to Yorkshire. The series has been divided into lower, middle, and upper groups, the most important beds in which are: In the lower group, the *Inferior Oolite*, a coarse, often very shelly, limestone, irregularly oolitic, and occasionally interlaminated with sand in the lower portion; the *Great Oolite*, a white oolitic limestone of variable thickness and character, having a series of sandy flags at its base, and shelly beds at the top, largely developed near Bath, where it forms the famous "Bath stone;" and the *Cornbrash*, a coarse, shelly and somewhat ferruginous limestone, in a very thin and variable, but remarkably persistent bed. In the middle group, the *Oxford Clay*, a dark blue and greyish clay, having in its lower portion subordinate bands of argillaceous limestones, and local beds of brown sand, and extending from Weymouth, in Dorset, to Filey Bay, in Yorkshire. And in the upper group, the *Kimmeridge Clay*, a greyish blue shaly clay, sometimes brownish or yellowish, containing bands of sand, or calcareous grit. In some places it becomes very bituminous, passing into a kind of poor imperfect coal.

In Scotland, near Brora, beds similar to the inferior oolites and containing impure coal occur; and patches of lias and Oxford clay are found along the western coast, and in the islands of Mull and Skye. In Ireland, the only beds belonging to this formation are some liassic shales in some parts of Antrim.

The Cretaceous Period.—The beds of the Cretaceous or Chalk Period are: the *Wealden Beds* of the south of England, consisting of the Hastings sands, fawn-coloured sands and sandstones, in some parts calciferous, in others ferruginous; and the Wealden clay, a thick blue clay, containing in its upper part septaria of argillaceous ironstone; the *Lower Greensand*, a greenish ferruginous sand, containing layers of calcareous grit and sandy limestone; the *Gault*, a bluish tenacious clay; and the *Chalk*, divided into two groups, the lower and the upper, the latter being softer and whiter, and containing more flints than the former, which becomes reddish to the north of Cambridgeshire. The chalk formation is most abundantly developed in the south of England.

The Eocene, Miocene, and Pliocene Periods.—These periods include all the deposits of the tertiary epoch, with the exception of a few of more recent origin, to which the names of "pleistocene" and "modern" have been applied. These beds are developed chiefly in the south-east part of England, and are therefore of little importance to the miner.

Organic Remains.—We have already explained and described the order of superposition of beds, and pointed out the means which this order furnishes for determining the relative age of any bed or set of beds. The observations of palæontologists have disclosed an analogous order of superposition among the fossil remains existing in the beds. Species and genera which formerly existed have given place to newer species and genera, and these again have been supplanted by others of more recent origin. Some are found only during one age, others extend throughout a whole period. The species do not die out suddenly, but pass by insensible gradations into other species. But a sufficiently definite line may be drawn for practical purposes. It follows from this that when the order of succession of the groups of rocks has been established by direct observation in one district, and the characteristic fossils of each group have been determined, these fossils may be used to identify the groups in another district where, perhaps, their order of succession is not open to direct observation. Here, then, we have another and a very reliable means of identifying rock-beds. The mere lithological character of beds is often deceptive; but the evidence of fossils is conclusive. From what has already been said concerning the manner and place of deposition of the three kinds of rocks—limestones, sandstones, and clays—it might be inferred that each kind would enclose different and characteristic species of fossil organic remains, since the conditions of life would be favourable to some and unfavourable to others. The shallow, troubled waters of the sandstones; the deep, turbid waters of the clays; and the still, clear waters of the limestones, would be inhabited by only such forms of life as were capable of existing under the physical conditions peculiar to each case; and as a matter of fact, the inference is found to be generally true. The practical value of this means of identification can hardly be over-estimated. The following remarks by the late Mr. Jukes, of the Geological Survey, on this subject, are worthy of the attention of practical men: "Within my own experience, large sums of money have been absolutely thrown away, which the slightest acquaintance with palæontology would have saved. I have known, even in the rich coal district of South Staffordshire, shafts continued down below the coal measures deep into the silurian shales, with crowds of fossils brought up in every bucket, and the sinker still expecting to find coal in beds below those silurian fossils. I have known deep and expensive shafts sunk in beds too far above the coal measures for their ever being reached, and similar expensive shafts sunk in black shales and slates in the lower rocks, far below the coal measures, where a pit might be sunk to the centre of the earth without ever meeting with coal. Nor are these fruitless enterprises a thing of the past. They are still going on, in spite of the silent warnings of the fossils in the rocks

around, and in spite of the loudly-expressed warnings of the geologists, who understand them, but who are supposed still to be vain theorists, and not to know so much as 'the practical man.'"

The fossil remains of each geological period include species far too numerous for illustration in a work not devoted to palæontological considerations. To acquaint oneself with the whole of these species in their multitudinous varieties, and in all their suggestive and highly interesting relations, is the labour of a lifetime, and therefore utterly beyond the reach of him whose duties involve the conduct of practical operations. Nor is it desirable that he should possess such knowledge, even if it were obtainable at a less cost of time; for much of it bears but very remotely, and some not at all, upon the subjects to which his attention is specially directed. It will, however, be evident from the foregoing statements concerning its bearing upon the relative age of rock formations, that the fundamental principles of palæontology and the main facts of that science demand his careful study, as constituting an essential part of his practical knowledge. And having acquired this, he should make himself familiar with the commonest and the most characteristic forms of the organic remains of each period, as illustrations which he may every day turn to useful account. Such forms, reduced to the fewest possible number, are included in the following classifications, and will be found delineated upon Plates VII. to XII. inclusive.

Characteristic Fossil Remains of the Silurian Period.

Radiata (*ray or star-like*).—Hydrozoa (*water animals*), *Rastrites*, *Graptolites*, *Diplograpsus*, *Didymograpsus*. Echinodermata (*spiny skin*), *Echinosphærites*, *Caryocystites*, *Sphæronites*.

Articulata (*jointed*).—Crustacea (*crab class*), *Asaphus*, *Ampyx*, *Calymene*, *Trinucleus*, *Ogygia*, *Olenus*, *Agnostus*, *Illænus*, *Hymenocaris*.

Mollusca (*soft animals*).—Brachiopoda (*arm-footed*), *Lingula*, *Orthis*, *Strophomena*, *Leptæna*, *Pentamerus*. Lamellibranchiata (*plate-gill*), *Avicula*. Encephala (*having a head*), *Murchisonia*, *Euomphalus*, *Bellerophon*. Cephalopoda (*head-footed*), *Orthoceras*.

Characteristic Fossil Remains of the Devonian and Old Red Sandstone Period.

Mollusca.—Brachiopoda, *Spirifera*, *Calceola*, *Stringocephalus*. Lamellibranchiata, *Megalodon*. Encephala, *Murchisonia*. Cephalopoda, *Clymenia*.

Vertebrata (*back-boned*).—Pisces (*fishes*), *Dipterus*.

Plants.—*Adiantites*.

Characteristic Fossil Remains of the Carbon Period.

Radiata.—Hydrozoa, *Archimedipora*, *Ptilopora*, *Fenestrella*. Anthozoa (*flower animals*), *Lithostrotion*, *Lithodendron*, *Amplexus*, *Syringopora*, *Woodocrinus*. Echinodermata, *Pentremites*, *Pateriocrinus*, *Palæchinus*, *Archæocidaris*.

Articulata.—Crustacea, *Beyrichia*, *Dithyrocaris*, *Bellinurus*.

Mollusca.—Brachiopoda, *Terebratula*, *Rhynchonella*, *Spirifera*, *Athyris*, *Orthis*, *Productus*. Lamellibranchiata, *Aviculopecten*, *Posidonomya*, *Posidonia*, *Anthrocoptera*, *Anthrocosia*. Encephala, *Conularia*, *Euomphalus*, *Bellerophon*, *Loxonema*. Cephalopoda, *Nautiloceras*, *Goniatites*, *Orthoceras*.

Vertebrata.—Pisces, *Pleuracanthus*, *Cochliodus*, *Orodus*, *Psammodus*.

PLANTS.—*Fruit of Calamites, Trigonocarpon, Lepidostrobus, Sigillaria, Lepidodendron, Calamites, Asterophyllites, Spenopteris, Pectopteris, Neuropteris, Cyclopteris, Odontopteris, Otopteris.*

CHARACTERISTIC FOSSIL REMAINS OF THE PERMIAN PERIOD.

RADIATA.—Bryozoa (*moss animals*), *Synocladia, Fenestrella.*

MOLLUSCA.—Brachiopoda, *Producta, Strophalosia, Spirifera, Camarophoria.* Lamellibranchiata, *Schizodus, Mytilus, Pleurophorus.* Encephala, *Macrocheilus.*

VERTEBRATA.—Pisces, *Platysomus, Palæoniscus* (*scales of*), *Cœlacanthus, Pygopterus, Acrolepis.*

LABYRINTHODON REMAINS OF THE TRIASSIC PERIOD.

Footprints of Labyrinthodon; teeth of the same.

CHARACTERISTIC FOSSIL REMAINS OF THE LIAS.

RADIATA.—Echinodermata, *Extracrinus, Ophioderma.*

MOLLUSCA.—Brachiopoda, *Spirifera, Terebratula.* Lamellibranchiata, *Gryphæa, Avicula, Ostrea, Hippopodium.* Encephala, *Pleurotomaria.* Cephalopoda, *Ammonites, Belemnites.*

VERTEBRATA.—Pisces, *Acrodus, scales of Echinodus, Dapedius.* Reptilia (*reptiles*), *Ichthyosaurus, Plesiosaurus.*

GEOLOGICAL SURVEYING.—The making of Geological Surveys constitutes one of the most important duties of the mining engineer. This kind of work does not, indeed, enter largely or definitely into his ordinary occupations as do many of his other duties connected with the active management of a colliery. But he may at any moment be called upon, and frequently is called upon, to inspect and report upon a supposed extension of a known coal-field, or a newly-discovered field in some new district, in, perhaps, a new country. To do this, he must not only possess the requisite geological knowledge, but he must also know how to apply it so as to enable him to solve the problem in question, and how to present the results of investigations so as to be intelligible to other persons. Moreover, even in the sinking of new pits in well-known districts where he is not closely surrounded by old workings, he will have to estimate from data obtained from a survey the dip of the seam to be won, the depth at which it will be struck, its strike, and other conditions of primary importance to the success of the undertaking. Hence it may be assumed that the following brief directions for the production of geological plans and sections will not be considered as forming an inappropriate close to the present chapter.

Character of Rock-Beds.—Being provided with the means of determining the nature of rocks, as already described, the first thing to be done is to procure a map of the district to be surveyed, to a scale of six inches to a mile, or thereabout. If no such map exists, one will have to be made. This map should then be cut up into portions of a convenient size for use in the field. In commencing the survey, the observer should make himself acquainted with the geography of his district by traversing it in various directions, and viewing it from elevated positions, so as to get a thorough knowledge of its surface configuration, and in doing this he should note the lithological character of the most prominent rock masses. The detailed survey may then be proceeded with by examining carefully the whole surface of the ground, and indicating the character of the rocks of which it is composed by conventional signs previously determined upon. This part of the survey is beset with difficulty in consequence of the existence of vegetable soil. Hence the observer will have to seek

spots where the rocks are exposed, and these exposed portions he must mark down on his map in the exact space which they occupy. When igneous rock is met with, its character must be observed, and its mode of occurrence noted, that is, whether it be intrusive or otherwise. Obviously the accuracy of the inferences drawn will depend, first, upon the abundance of the data; in other words, upon the number of places where the rocks are exposed; and, second, upon the care with which the observations are made. This remark applies equally to the points to be hereafter considered.

Dip and Strike of Rock-Beds.—While making himself acquainted with the character of the rock-beds, the observer must be careful to ascertain their dip. For this purpose, he will have to seek localities where a "section" can be seen. The best exposures of this character will be found in ditches, road-sides, pits, quarries, banks of streams, railway cuttings, wells, mining shafts, or any surface openings that may occur. In taking the dip, he must be ever on his guard lest he be misled by oblique lamination, cleavage, or other indications of cross fracture, or by layers displaced by the growing roots of trees. The amount of the dip is measured in degrees by means of a clinometer, and its direction is determined by the aid of a pocket-compass. To ensure accuracy, the dip should be measured and the character of the rock noted wherever a square foot can be found exposed. In examining sections, the observer should endeavour to obtain a view of a group of rock-beds, in order that when he meets with an exposure of any one of them, he may be able to infer the position and thicknesses of the others. The dip is indicated on the map by means of an arrow placed in its proper position with respect to the north point, and marked with the number of degrees. Thus, arrows pointing in contrary directions will denote an anticlinal curve, while arrows pointing towards each other will indicate the existence of a synclinal curve. Every change in the amount and the direction of the dip demands careful attention. Such changes may be merely local or superficial flexures, instead of belonging to the great and general bendings of the rocks. And it must be borne in mind that when one fold dies out, and another begins at the same time to rise on one side or the other, there will be, as a consequence, transverse strikes over the district between the approximate ends of the two folds. And also that when the dip is slight, the variations in the strike are often great; and that, therefore, a careful comparison of all the results over a wide range of country, and of the bendings indicated, may be necessary, to ascertain the true direction of the axis of elevation. As the strike is at right angles to the line of direction of the dip, the latter will, of course, determine the former.

Boundaries of Rock-Beds.—When the character and the dip of a bed have been determined, its upper and lower boundaries should be laid down on the map. In tracing these boundaries on the ground, the observer should bear in mind that when the surface is uneven, the strike of the bed will not correspond with its line of outcrop. It is obvious that when the angle of the dip is low, a slight undulation of the ground will cause the outcrop to deviate widely from the line of its strike. Also a slight change in the strike or in the amount of the dip will produce a much greater effect than when the beds are inclined at a high angle. The observer must likewise endeavour to keep in his mind the ascertained thickness of the bed he is tracing, and the relation of the changes in the dip and the strike to the different features of the surface. It will be evident from what has been said respecting the thinning out of rock-beds, that the bed which is being traced may, within a short distance, change its character from a sandstone to a shale, or from a shale to a limestone. Also if it retain a uniform composition it may change completely in colour within a few yards, so as to be no longer recognizable by the mere appearance. Such changes are not to be regarded as producing a new bed.

Faults.—The direction of dykes must be accurately laid down upon the map, as determined by the magnetic needle, and their character indicated. The boundaries should be carefully traced, and their effects upon the contiguous strata noted during the survey. Faults of dislocation demand particular attention; and here the observer should be cautioned against hastily drawing the conclusion that a fault exists, from certain appearances which at first sight seem to warrant such a conclusion. And this caution is especially necessary when the suspected fault is the first observed in the district. In such a case, absolute proof should be required. When one line of fault has been proved beyond all question to exist, there must be almost necessarily others, either parallel, or at nearly right angles to it. Respecting the existence of these, therefore, a less amount of evidence may be sufficient. But when an appearance may be accounted for on any other grounds than the presence of a fault of dislocation, there is reason for further observations before arriving at a decision. When, however, a dislocation has undoubtedly occurred, the character and the amount of the throw must be ascertained; and in observing these, the apparent lateral shift, and other effects previously described, must be borne in mind.

Besides geological plans, "*sections*" are needed to show the relations of the beds to each other, that is, their lie and relative position. The section shows the direction and amount of their inclination beneath a horizontal plane, and the depth attained by any given bed under any spot at a given distance from its outcrop. In preparing such a section, a horizontal datum line is assumed, and the beds drawn with their proper angle of dip with this line. The undulations of the surface are also drawn in with reference to this datum line. The line of section is generally taken at right angles to the strike, so that the section shows the true dip of the beds. Before, however, a section can be drawn, the thickness of the beds whose boundaries have been previously laid down on the plan must be determined.

Thickness and Depth.—When the upper and lower boundaries of a bed, in other words, its basset edges, have been determined, and the amount and direction of its dip ascertained, its thickness, its depth, or the vertical distance through it, and the distance from surface at which it will be met with from any given point may be easily calculated. For this purpose it is only necessary to measure the width of the basset edge of the bed, or group of beds, at right angles to the strike. This width must be measured in a horizontal line, and therefore, if the surface of the ground is inclined or undulating, the horizontal distance must be determined by the ordinary methods. For example, suppose we wish to know the thickness of the beds comprised between the points a and d, Fig. 4, Plate II. Let l be the horizontal distance between a and d, and θ the angle of the dip. Then the thickness of the beds $a\ b$, measured at right angles to the dip, will be given by the formula,

$$t = l \text{ sin. } \theta.$$

So, also, the depth of the beds, that is, the vertical distance from the point a to the point c. will be given by the formula,

$$d = l \text{ tan. } \theta.$$

It is obvious that the thickness and depth of any given bed, and its distance from surface at any given distance from its outcrop, may be readily determined in this way.

It will also be evident that if a table of natural sines and tangents be constructed to, say, four places of decimals for the whole angles—for the minutes are practically useless,—we may ascertain the thickness and depth by mere inspection; and, moreover, that such a table may be used for

calculating the space between the outcrop of two beds whose angle of dip is known, and the thickness between them; and the distance at which any bed, whose depth and inclination are known, will crop out to the surface. Also the probable throw of a fault may be ascertained from the table, when the ends of a bed can be found on both sides of a fault, and a mean angle of dip assigned to the whole mass. For example, if we have a bed, as *a a*, in Fig. 20, Plate IV., traversed by a fault *b b*, and the outcrops be found in such a position that the distance *c b* can be measured, the table will give us the depth which the downcast portion has attained in the distance *c b*, which depth will, of course, be the amount of throw of the fault. Indeed, such a table is of continual use to the practical geologist.

Oblique Sections.—In most cases, the line of section is taken at right angles to the strike, and such sections will, of course, show the true dip of the beds. But circumstances may exist which render an *oblique* section desirable, that is, one that shall cross the line of the dip at an acute angle; and, indeed, in running a section across a greatly disturbed district, it will almost of necessity cross the line of the dip obliquely in some parts. It may even happen that the line of section will run along the strike. In the latter case, the beds will appear horizontal in the section, and their *apparent* will not be their *true* thickness, but will be greater than their true thickness. Also, when the line of section crosses the line of dip obliquely, the apparent will not be the true dip, but will be less than the true dip. In order to draw such a section correctly, the necessary correction of the true dip must be made by means of the following formula, due to Mr. Hopkins, past President of the Geological Society:

$$\text{tan. } z = \frac{\text{tan. } y}{\text{sec. } x}, \text{ or log. tan. } z = \text{log. tan. } y - \text{log. sec. } x;$$

in which z is the angle of the apparent dip, y that of the true dip, and x that of the line of section with that of the true dip. The angle x is always to be calculated on that side of the line of section where the angle is less than 90°. And it is evident that the direction of the dip corresponding to a given angle on one side of that line, will be contrary to that corresponding to the same angle on the opposite side. It is important that the correction for the apparent angle should be carefully attended to, not only for the purpose of accurately representing it, but also for determining the depth of beds, and for drawing in the true angle of lines of faults, veins, dykes, and cleavage planes. The following table, calculated from the above formula, gives the correction for the most useful angles:

OBLIQUE SECTION TABLE.

Angle of the Section = x.	Angle of the Dip = y.											
	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
5	4 59	9 58	14 57	19 56	24 55	29 50	34 54	39 51	44 53	49 54	54 54	59 54
10	4 55	9 51	14 47	19 43	24 40	29 37	34 35	39 34	44 34	49 34	54 35	59 37
15	4 50	9 40	14 31	19 22	24 15	29 9	34 4	39 2	44 0	49 1	54 4	59 8
20	4 42	9 25	14 8	18 53	23 40	28 29	33 21	38 15	43 13	48 14	53 18	58 26
25	4 32	9 5	13 39	18 15	22 54	27 37	32 24	37 15	42 11	47 12	52 19	57 4
30	4 20	8 41	13 4	17 30	22 0	26 34	31 14	36 0	40 54	45 54	51 3	56 18
35	4 6	8 13	12 23	16 36	20 54	25 19	29 50	34 30	39 19	44 56	50 20	54 49
40	3 50	7 42	11 36	15 35	19 39	23 51	28 16	32 44	37 27	42 25	47 34	53 0
45	3 32	7 6	10 44	14 26	18 15	22 12	26 21	30 41	35 16	40 7	45 17	50 46
50	3 13	6 28	9 47	13 10	17 28	20 22	24 14	28 20	32 44	37 27	42 33	48 5
55	2 52	5 46	8 44	11 47	14 58	18 19	21 53	25 42	29 50	34 21	39 19	44 59
60	2 30	5 2	7 38	10 19	13 7	16 6	19 17	22 45	26 34	30 27	35 32	40 54

CHAPTER II.

COAL: ITS MODE OF OCCURRENCE, COMPOSITION, AND VARIETIES.

ROCKS ASSOCIATED WITH COAL.—Though coal is found, in several parts of the world, among rocks of different periods, practically it may be considered as existing only among those of the Carbon Period, so called on account of the occurrence of abundant coal deposits. For in no other period are the deposits of sufficient extent or of sufficient quality to be commercially valuable. Hence, searching for coal in any other formation is a labour holding out but faint hope of reward, and discoveries of deposits in such situations merit but little attention from a practical point of view.

The coal measures consist, as we have stated, of an alternation of sandstones and argillaceous rocks, with occasional seams, beds, or bands of coal and ironstone. The sandstones vary in texture from the finest grained rock to the conglomerate. The fine-grained varieties, however, largely predominate. They are frequently micaceous, and of various degrees of hardness. The finer the particles of which a sandstone is composed, the larger is the proportion of quartz present, and, generally, the more strongly agglutinated is the rock. The cement which serves in most cases to agglutinate the particles is silica, and when present in large proportions, the rock requires much labour and time to cut through, and occasions a rapid wear of the tools employed. When a sandstone is micaceous, it becomes brittle, and quickly crumbles on exposure to atmospheric agencies. The ability of a rock to withstand the disintegrating action of these agencies may be known in great measure by its avidity for moisture, the more absorbent being the less durable. The fine-grained sandstones generally form thick and homogeneous beds, extending over large areas; the coarse-grained have been deposited mainly in troughs and basins. The sandstones of the coal measures are white, yellowish grey, or pale blue; sometimes they are coloured reddish or brownish by a ferruginous cement, and occasionally blackish by the presence of carbon.

The argillaceous rocks consist sometimes of thick beds of plastic clay, more frequently of thinner beds of indurated schistous clay, called "shale." The foliated structure of these shales is exhibited in numerous thin laminæ varying considerably in colour, hardness, and fineness of grain; in occasional layers of mica; in vast numbers of vegetable impressions between the laminæ, when lying immediately above the coal; and especially in the property which the rock possesses of swelling as it absorbs the moisture of the atmosphere, and finally separating into thin laminæ. The surfaces of these laminæ are soft and unctuous to the touch, like plastic clay, and adhere to the tongue. If placed in water, shale moulders into powder. The shales are the most distinctly coloured of all the rocks of the carboniferous formation; generally they are of a bluish or yellowish grey colour, more rarely of a dark blackish or reddish grey, or greyish black, or greenish colour. The black hue is probably due to the presence of bituminous matters, for when exposed to the action of

fire this colour disappears. These bituminous or carbonaceous matters are sometimes present in large proportions. They have been derived from vegetable remains deposited with the earthy materials of which the shale is composed, and, in some cases, from the gases evolved from underlying seams of coal. Such shales are called *bituminous*, and when rich in characteristic matters, they constitute a valuable source of mineral oil. They are less fissile, more compact, and more sonorous than the common shales, which they resemble exactly in external appearance. A peculiarity which clearly distinguishes them from the common or slightly bituminous shales lies in the fact that when a thin paring is cut along a surface, it curls up before the knife, and leaves a brown, lustrous streak. This peculiarity is very distinctly marked in some of the Scotch shales. Bituminous shale burns with abundant flame, emitting a dense smoke, and leaving as a residue the pure shale, white, and reduced to thin laminæ.

In most cases, a bed of shale lies immediately beneath and immediately above a seam of coal. That which lies beneath, and which is known as the under clay, forming the floor, thill, or seat of the coal seam, generally consists of a more dense and plastic clay than that which lies above the seam, and forms its top or roof. The under clay formed the soil upon which the plants grew from which the coal is derived, and, as might have been expected, it contains numerous traces of roots. These traces consist of dark, carbonaceous, fibrous-looking streaks, traversing the mass in all directions. Sometimes the rootlets are preserved in a more distinct form. It is remarkable that nothing but roots are found in the under clay. The most common are stigmaria, the roots of the sigillaria. This under clay usually constitutes a fire-clay, and when of the requisite composition and degree of hardness, it becomes of great value for brick making, and other purposes where materials of a refractory nature are required. As the under clay originally formed the soil upon which the coal plants grew, we might expect that it would be everywhere and invariably present, and as a matter of fact it is so generally, the exceptions being of rare occurrence. Whenever the under clay is absent, it may be inferred that the materials of which the coal was formed were drifted into their present situation. The existence of the under clay greatly facilitates the extraction of the coal. The shale of the roof is of a more indurated character than that of the floor, its structure being that of a true shale. It contains remains of plants in wonderful profusion, rivalling in variety the collections of princely conservatories. Erect stumps of sigillaria often exist in the roof shale; sometimes vast numbers are found within a small area. They are pretty uniformly scattered over the seam, and appear to have grown upon the surface of the coal, into which their roots have been incorporated. Generally these stumps are but a few feet in height, but they may be as much as six feet in diameter at the base. Being conical in shape, they are liable to drop out suddenly after the coal has been removed from beneath them, and as their weight may be little short of a ton, they constitute very dangerous associates of the shale roof in workings. They are known to the colliers as "pipes," "pot-bottoms," and "bell-mouths," and have to be carefully watched and propped. Their circular outline may be traced in the shale of the roof. The character of the shale constituting the roof is of considerable practical importance, a strong, highly tenacious shale being the most favourable to ease and economy of working. The roof shale is more frequently absent than the under clay, and its absence is decidedly detrimental to the quality of the coal.

Bands of nodular ironstone, of variable thickness and irregular in extent, occur in most of the coal-fields of Great Britain, and constitute one of the chief sources from which our supply is derived. These concretions, which form layers in shale or clay, are sometimes of very small size, and are

locally designated by such names as "Pins" or "Pennystones," as, for example, the Pin-ironstone seam of Staffordshire. Sometimes they are large spheroidal masses, several inches and even one or two feet in diameter. In some instances a band of clay-ironstone occurs as the roof of a coal seam. There are many districts, notably in North Staffordshire and parts of Scotland, in which seams of ironstone are found containing a large proportion of carbonaceous matter; these are known as "black bands."

Mode of Occurrence and Origin of Coal.—Coal occurs as beds or seams interstratified with the sandstones and shales of the Carbon Period. It is not the result of a deposition, like the sandstones and shales, nor had its materials the same origin. The aqueous rocks are formed of the same elements as the igneous rocks, from which they have obviously been derived. But coal is composed of the elements which enter into the composition of vegetable organisms, namely, carbon, hydrogen, and oxygen, though the proportions are different. An examination of its structure reveals evidence of abundant vegetable remains—evidence which is strengthened by the existence of innumerable roots in the under clay. Indeed, there can be no doubt that coal seams are the remains of a former mass of luxuriant vegetation: of submerged pine-forests, jungle growths, and peat-mosses. In most cases these masses were covered up by new deposits on the spots on which they grew; but sometimes they were drifted into other situations previously to the deposition of the overlying beds. The action of chemical agencies, and the enormous pressure of the superincumbent rocks, have produced in these so-called deposits those changes of composition and structure which distinguish the coal seams from the peat-bogs of the present day. Deriving their origin from such a source, coal seams must necessarily vary greatly in thickness, since the vegetation of one age, or of one place, would differ widely in character, luxuriance, and length of existence from that of another age or place; and as a matter of fact, we find seams varying from one inch to thirty feet and upwards in thickness.

As coal occurs in beds interstratified with the aqueous rocks, it is subject to all the accidents which the latter are subject to; that is, to all those various effects which in the preceding chapter have been described as "Faults," and "Results of Denudation." These having been fully described in relation to the soft aqueous rocks, need no further remark here.

Composition of Coal Seams.—A block of compact coal, though differing essentially in origin and mode of formation from a similar block of shale, is yet, like the latter, made up of thin laminæ. These laminæ are frequently slightly undulating, and they vary considerably in texture and thickness. It is, however, worthy of remark that the thickness is invariably greater in the lustrous than in the non-lustrous varieties. The character of the laminæ, too, is very variable, not only in different localities and in different seams, but even in the same block of coal. Some experiments, undertaken by M. Burat, for the purpose of investigating this remarkable phenomenon, showed that in those instances which, on these occasions, came under his observation, there was an alternation of laminæ composed of a homogeneous, compact, specular, and very light substance, giving less than 2 per cent. of ash, with others of a less pure composition, being largely mixed with earthy matters, and leaving from 20 to 25 per cent. of ash. Other variations occur among the laminæ of coal; sometimes in the most bituminous qualities, laminæ of an anthracitous character are occasionally present.

When a seam is of considerable thickness, it rarely constitutes a compact and homogeneous mass, but is formed of two or more beds. These beds are separated from each other, sometimes

by a simple plane of division, sometimes, and more frequently, by an interstratified bed of earthy material. Such planes of division are called "partings," the latter kind being distinguished as "dirt partings." Partings constitute a very important feature of coal seams. The more numerous they are in a seam of a given thickness, the smaller will be the blocks of coal extracted. But of greater moment is the impurity which they are liable to occasion when formed of an intercalated bed of carbonaceous shaly matters. Being in most cases of a very tender and friable character, they fall with the coal, and become intermixed with the smaller portions. The labour of picking out the partings when they are numerous or thick adds materially to the cost of getting the coal, and the reduction in the size of the blocks caused by the presence of the partings, and the impurity which, in some degree, they inevitably occasion, lessens the value of coal when got. This is especially the case when the coal is tender and friable. If, however, the partings are few, and only three or four inches in thickness, their presence is greatly advantageous to the miner, inasmuch as it enables him to undercut or hew the coal along these partings.

The plane of division between the coal and the shale of the roof is often an imperceptible one, the two surfaces so adhering that when the coal is worked away, either a few laminæ of the latter remain suspended to the roof, or, if the shale is tender, a few laminæ of the roof material may come away with it. Sometimes the plane of division is clear and distinctly determined; in such cases the coal will come away clean. The same remarks apply to the partings.

The several beds of coal of which a seam is made up are rarely identical in quality, and, as a general rule, it will be found that the thicker the parting the greater will be the difference in the quality. Thus the same seam may furnish several qualities of coal. This circumstance has always to be taken into consideration in valuing the product of a seam. The difference in quality of the several beds may assume various forms. Thus one may be of a more bituminous character than another, or it may be thinner, and thus furnish smaller blocks; or it may be more mingled with impurities; or, again, it may be more tender and friable, in which case the seam will yield simultaneously large and small coal proportionately to the thickness of each bed. All of these circumstances materially influence the value of the seam.

The constituents of coal we have already stated to be carbon, hydrogen, and oxygen. These constituents, however, never exist pure, but are more or less intermixed with other matters. The impurities may be classed as essential and accidental; the former being those which entered into the composition of the vegetable substances from which the coal was formed, and the latter those which have been intermixed with these substances. The essential impurities consist of silica, alumina, lime, magnesia, and oxide of iron, to which may be added water. The accidental impurities may consist of any substance other than the three elements mentioned. Some of these have been introduced by the infiltration of water holding the substances in solution. In general, the accidental impurities consist of earthy matters, which were probably deposited from water flowing among the coal vegetation, or blown thither by the winds. The quantity of earthy impurities present in any given sample of coal is estimated by weighing the ash after combustion. When the weight of the ash does not exceed 5 per cent. of that of the coal, the latter is considered very pure. Above that proportion, it begins to lose in quality, and becomes hard and shaly in structure.

A common impurity is *iron pyrites*, or bisulphide of iron, a substance known to coal miners as "brasses," and hence seams containing it are described as "brassy." Pyrites occurs sometimes as a deposit filling the cracks and fissures in the coal; sometimes as thin

intercalated beds. It is not unfrequently met with running with a line of parting; occasionally it occurs as cubical and octahedral crystals disseminated throughout the mass; and more often as minute particles imperceptible to the naked eye. The presence of iron pyrites detracts greatly from the value of coal by rendering it unsuitable for many important uses. Coal containing this mineral is totally unfit for metallurgical purposes, and it cannot be burned anywhere in contact with iron without serious injury to the latter. Hence it cannot be employed for the generation of steam, as its corroding action would rapidly destroy the fire-grating and the lower plates of the boiler. Moreover, pyrites is decomposed by moisture and converted into a sulphate, and the expansion which takes place during the process tends to break the coal into very small lumps, and even to a powder. This decomposition is often accompanied with great heat, and spontaneous combustion is not unfrequently occasioned thereby. Heaps of brassy small coal and rubbish, lying as refuse on the pit-bank, often take fire from this cause in wet weather, and, which is of far more disastrous consequence, the exposed coal in the workings will sometimes become ignited. When pyrites occurs as layers, especially when running with a line of parting, it may be picked out without much labour or expense; but when occurring otherwise, the separation cannot, in practice, be effected.

Coal seams, even of the same variety of coal, differ from each other considerably in physical condition. Some are very soft and tender. Such seams require but little labour to work, but the coal is extracted in small blocks, and is therefore of less value in the market. It also gets much broken by the repeated operations of loading, unloading, and conveyance, which, besides lessening the value still further, render it unfit for many uses. Coal of a tender, friable character is described by the miner as "mingey," and "dicey" when it breaks into small cubical fragments like dice. Hard seams furnish strong coal in large blocks, but they require much greater labour to work them. Sometimes seams, even of hard coal, are much broken and traversed by joints. In such cases, the seam will make a large proportion of small coal, and frequently the quality will be found to have undergone deterioration in other respects. Even the most compact seam may become much broken on approaching a fault. The intrusion of dykes and veins of igneous rock will often injure the contents of a coal seam for considerable distances. Some seams give off large quantities of carburetted hydrogen gas, and thereby necessitate additional care and expense in the working. All of these "accidents" may be considered general, because every seam is liable to be affected by one or more of them. Others there are of a more local character, but equally requiring to be taken into consideration when estimating the value of a coal seam.

The Cleat, Slyne, or Face of Coal.—Coal being made up of laminæ cleaves most readily along the planes of stratification, like a shale or any other laminated rock. It is also regularly traversed by the joints which run through the rocks associated with the seam. But besides these, it is divided into smaller cubical blocks by two sets of joints running at right angles to each other, and at right angles to the planes of lamination. One of these sets is more persistent than the other, and gives a more smooth and even face. This set constitutes what is called by miners the "cleat" or "slyne" of the coal, and the even surface produced by it is called the "face," in opposition to the more irregular surface produced by the other set, which is called the "back" or "end." These cleavage planes, which are but slightly analogous to those of cleavage as already defined, are persistent over very large areas; the direction may, however, be changed by a fault. In some districts both sets are very distinctly developed; in others, one set becomes confused and faint. Occasionally these planes

are oblique to those of lamination, or to each other, and in such cases the coal divides into wedge-shaped or angular blocks. The fresh surfaces formed by these planes of cleavage soil the fingers much less than those corresponding with the planes of lamination.

The cleat of coal, which may be clearly seen in hand specimens, is a true joint structure, occasioned by the shrinkage consequent on desiccation, its more perfect development in the coal than in the adjacent rocks being due to the greater tenderness of the former. And hence it is that this peculiar structure is more fully developed in the more tender varieties of coal. The cleat is of very great importance in mining, inasmuch as the direction of the workings is determined thereby.

Distinctive Characters and Identification of Seams.—In consequence of the interruptions occasioned by faults, denudation, and other accidents, it is impossible to identify a seam of coal from its position alone. The upper seam in one portion of a coal-field may not be identical with the upper seam in another portion of the same field, and if we take two separate districts, the upper seam of the one may be the lower seam of the other. It is, however, of the highest practical importance to identify the seam in any new winning, for by this means the whole composition of the field is made at once manifest, and in numerous instances the continuity of the field over an area that was previously thought to be barren, is clearly and indisputably established. In every geological survey, therefore, besides the evidence furnished by the adjacent strata, the characteristic features of a seam of coal as existing in one part require to be carefully noted to enable us to recognize it in another part. Such features are: the number of the layers or beds of coal of which the seam is composed; their thickness, quality, and physical condition; the character of the cleat; the nature of the partings, and of the substances composing them; the constitution of the floor and the roof; the fossil remains in the latter; the character of the adjacent rocks; and the position of the seam with respect to others previously determined. It must not be expected that when a seam is struck in a new part it will present all the characteristics which it possesses in another; frequently some will be altogether absent, while others will have undergone modification. But in no case will they be all absent or modified.

To trace the continuation of a seam of coal throughout a considerable distance when the ground has been much disturbed by faults and contortions, and the characteristic features as determined in another part have undergone frequent and considerable modification, is ofttimes a very difficult task. In such cases, assistance may be derived from the overlying rocks. A bed of sandstone, or of shale, may have preserved its distinctive character, when that of the coal has been all but destroyed, and the landmark thus preserved may enable the doubting miner to determine his position with certainty.

Classification of Coal.—Coal differs widely in chemical composition and in physical condition, not only from district to district, but from seam to seam in the same district, and, as we have shown, from bed to bed in the same seam. This variety necessitates a classification, both on scientific and commercial grounds; and several classifications have been proposed and more or less adopted, in accordance with each of these points of view. None of these, however, are sufficiently comprehensive to be satisfactory even in their own special domain, and hence recent writers have endeavoured to form a new and general classification which should be definite enough to group the most important qualities, and comprehensive enough to include all varieties.

By tracing the progress of the formation of coal through all its known stages, however, we arrive at certain definite facts upon which a satisfactory classification may be based. Derived originally from vegetable matters, coal has undergone since its submergence changes that have radically altered its

primitive nature. In colour, it has passed from white, through every shade of brown, to black. Its density has been more than doubled. Its constituent oxygen and hydrogen have partially disappeared. The former especially has been gradually and constantly eliminated, so that the solid combustible subjected to these modifications shows by its excess of carbon and its defect of oxygen the extent of the changes that have been produced. The relative decrease of the hydrogen is also clearly perceptible, though much less well marked than that of the oxygen. Thus we have three important effects of age, by means of which we may characterize any variety of coal: An increased proportion of carbon; a consequent augmentation of the specific gravity; and the ratio of the oxygen and nitrogen to the hydrogen $\frac{O + N}{H}$. In proportion as the oxygen diminishes, and consequently the proportion of water produced by distillation, the coal tends to become more friable, less sonorous, more dense, and of a blacker colour. Its brightness especially increases with the proportion of hydrogen; and with the hydrogen also, its caking quality. The readiness with which it ignites, and the abundance of its flame, depend upon the volatile matters which it contains. The varieties which are closely related to the lignites kindle readily, and burn with a long and fuliginous flame. Those which are less rich in volatile matters, and especially in hydrogen, kindle less readily and burn more slowly with less flame. The presence of impurities may greatly modify these qualities, but generally they will be found to exist, and any classification founded upon the conditions which produce them must be in the main satisfactory. Such a classification is the following, which divides coal into four classes, described as the *Anthracitous*, the *Semi-Bituminous*, the *Bituminous*, and the *Gaseous*.

Anthracitous Coal.—The seams of anthracite are the lowest in geological order, and they owe their distinctive character to their position. Having been more subjected than those above them to metamorphic agencies, they have undergone a greater amount of change. The volatile matters which originally entered into the composition of the coal have been expelled by heat, and hence the residue which we have in the form of anthracite partakes, in this respect, of the character of coke. Anthracite is the ultimate product of the conversion of vegetable matter into coal. Its structure is perfectly homogeneous, its density greater than the other kinds of coal, and it has a more completely mineralized appearance. Its colour is a jet black, with a somewhat vitreous lustre, often exhibiting a powerful play of colours. It does not soil the fingers when handled, being very hard and firm. Its specific gravity varies between 1·40 and 1·60. In the harder examples, the fracture is distinctly conchoidal, but when of a more tender character, it frequently breaks into small cubical lumps. Anthracite burns with a feeble flame, blue when the supply of oxygen is insufficient, and often decrepitates much in burning. It ignites with difficulty, and is slowly consumed, but when in a state of perfect combustion it evolves an intense heat. The proportion of carbon present is from 90 to 95 per cent., and that of the volatile matters never above 9 per cent. The quality of hardness possessed by anthracite enables it to be transported from one place to another without injury, while those of evolving great heat without smoke render it peculiarly suitable for many purposes, as, in certain cases, the generation of steam, and employment in distilleries, breweries, or in lime- or brick-kilns. In the United States of America, it is almost universally adopted for domestic use.

The coals which are classed with anthracite are those which possess similar physical properties, and contain not more than 12 per cent. of volatile matters. Of these, the anthracitous varieties of South Wales are the best known examples.

The elementary composition of this class may be represented as follows:

Carbon	90 to 95
Hydrogen	4·5 „ 3
Oxygen and Nitrogen	5·5 „ 2

Hence the ratio $\frac{O + N}{H}$ is rather less than greater than 1. The specific gravity varies between 1·40 and 1·60.

By distillation we obtain:

Coke	88 to 92	
Ammoniacal Liquor	·5 „ 0	Volatile matters, 12 to 8
Bitumen	3 „ 1	
Gas	8·5 „ 7	

The coke obtained from coals of this class is brittle, pulverulent, and useless for commercial purposes.

Semi-Bituminous Coal.—The term "bituminous," as applied to coal, is somewhat vague and deceptive. Bitumen includes several combustible substances, as asphalt, or mineral pitch, elastic bitumen, or mineral caoutchouc, naphtha, petroleum, and others, all of which are either fluids, or are readily soluble in alcohol, and the application of the term cannot with propriety be extended to substances of a different nature. But coal is not soluble in alcohol, and therefore cannot contain any real bitumen, though it may contain the constituents of it. Hence the term as applied to coal must be understood to mean that the mineralizing process has proceeded to a less extent than in anthracite, and, consequently, a larger proportion of the hydrocarbons remains.

Coal of the quality described as "semi-bituminous" occurs next above the anthracite in geological order. Occupying a higher position, it has been less exposed to the action of heat and other metamorphic agencies, and has consequently retained a larger proportion of its volatile matters. Between the anthracitous and the semi-bituminous classes, however, the line of division is purely arbitrary, since from anthracite to cannel there is every gradation of composition. Semi-bituminous coal contains from 12 to 18 per cent. of volatile matters. Its colour is usually a dull black, and its fracture sub-conchoidal. It frequently exhibits a peculiar fibrous structure, passing into a remarkable toothed arrangement of the particles, called "cone-in-cone," or "crystallized coal." It burns with a slightly more abundant flame than coals of the anthracitous class, and evolves more smoke, but not in dense volumes. It possesses the dry character of the latter class, and, from its freedom from a liability to cake together, it is sometimes called *free-burning* coal, and *steam* coal.

The elementary composition of this class may be represented as follows:

Carbon	89 to 92
Hydrogen	5 „ 4
Oxygen and Nitrogen	6 „ 4

Hence the ratio $\frac{O + N}{H}$ is not less than 1. The specific gravity varies between 1·35 and 1·40.

By distillation we obtain:

Coke	82 to 88	
Ammoniacal Liquor	1 „ 1	Volatile matters, 18 to 12.
Bitumen	5 „ 3	
Gas	12 „ 8	

The character of the coke obtained from coals of this class is similar to that obtained from those of the preceding class.

Bituminous Coal.—The bituminous seams occupy a higher position in the series than those last considered, and hence they contain a still larger proportion of volatile matters. The bituminous class is a very large one, containing numerous varieties of every degree of richness in volatile matters above the limit of the preceding class; and it therefore becomes necessary to subdivide it into three divisions, according to the proportion of the volatile constituents. These divisions may be described, from the qualities due to their composition, as the *clear-burning*, the *flaming*, and the *fuliginous*.

The varieties of the *Clear-burning* division are the poorest in volatile matters, the proportion of the latter being included between the limits 18 and 26 per cent. They are similar in texture to those of the preceding class, but generally of a duller lustre. They are very tender, and break with an even or an irregular fracture, and, in consequence of the very perfect development of the cleat, have always a tendency to break up into small cubical lumps. These coals kindle with difficulty, and burn away slowly with a short, clear, bluish flame, and very little smoke. When reduced to a powder and heated in a close vessel they fuse and agglomerate into a mass of dense and strongly coherent coke, a property which renders them extremely valuable for manufacturing purposes. Both in quality and in quantity the coke obtained from the clear-burning coals is superior to that produced by any of the more bituminous varieties.

The elementary composition of the clear-burning coals, as given by M. Grüner, is comprised between the following limits:

Carbon	88 to 91
Hydrogen	5·5 „ 4·5
Oxygen and Nitrogen	6·5 „ 4·5

Hence the ratio $\frac{O + N}{H}$ varies between 1 and 1·2. The specific gravity varies between 1·31 and 1·35.

Distillation gives, according to the same authority:

Coke	74 to 82	
Ammoniacal Liquor	1 „ 1	Volatile matters, 26 to 18
Bitumen	10 „ 5	
Gas	15 „ 12	

The coke obtained from coals of this division of the bituminous class is, as already remarked, of a very superior character.

The *Flaming* coals of the bituminous class are richer in volatile matters than the foregoing, a circumstance to which they owe their characteristic flaming quality. Their structure is distinctly laminated, and their colour black and glossy. When reduced to powder, however, their colour is a dark brown. They kindle without difficulty, and burn away somewhat rapidly with a long white flame. Coals of this character become partially fused when strongly heated, and while in a fused state swell into a spongy mass, giving off bubbles of gas, which burns with a bright flame. This property of agglutinating in the fire allows the small coal to be burned which would otherwise be useless, or to be converted into coke, of which it produces an excellent quality. To this property, also, these coals owe the name of *caking* coal, which has been applied to it in common with some other varieties of the same class.

The elementary composition of the flaming coals is comprised between the following limits:

Carbon	84 to 89
Hydrogen	5 „ 5·5
Oxygen and Nitrogen	11 „ 5·5

Hence the ratio $\frac{O + N}{H}$ is between 1 and 2. The specific gravity varies between 1·29 and 1·31.

Distillation gives:

Coke	68 to 74	
Ammoniacal Liquor	3 „ 1	Volatile matters, 32 to 26
Bitumen	13 „ 10	
Gas	16 „ 15	

The coke obtained from coals of this division of the bituminous class is of excellent quality.

The *Fuliginous* coals of the bituminous class contain a very large proportion of volatile matters. Hence they kindle readily, and burn away rapidly with a long, yellow, fuliginous flame. It is to this latter circumstance that they owe their name. They are somewhat hard and strong, and their fracture is rather shaly than even or conchoidal. Coals of this character fuse in the fire like the flaming varieties, but they do not agglomerate into so compact a mass. The gas obtained from them is abundant and of a high illuminating power.

The elementary composition of the fuliginous coals is comprised between the following limits:

Carbon	80 to 85
Hydrogen	5·8 „ 5
Oxygen and Nitrogen	14·2 „ 10

Hence the ratio $\frac{O + N}{H}$ is between 2 and 3. The specific gravity varies between 1·25 and 1·29.

Distillation gives:

Coke	60 to 68	
Ammoniacal Liquor	5 „ 3	Volatile matters, 40 to 32
Bitumen	15 „ 12	
Gas	20 „ 17	

The coke obtained from coals of this division of the bituminous class is friable and porous, and unfit for many purposes.

Gaseous Coal.—Coals of the class denominated "gaseous" occupy the highest geological position, some of them occurring in formations more recent than those of the Carbon Period. They are distinguished by the very large proportion of volatile matters which they contain, and to this circumstance it is due that they do not cake when heated. Experience has shown that coal becomes caking when the proportion of carbon reaches 80 per cent., and that of the oxygen descends below 15 per cent. On the other hand, when the proportion of hydrogen becomes very small and that of the carbon large, as in the anthracites, the same non-caking qualities result. The gaseous coals are of a brownish black colour, and of a dull lustre. When reduced to powder they are quite brown. They are generally hard, compact, and strong; their fracture is even to conchoidal. Coals of this class kindle even more readily than the fuliginous varieties of the preceding class, and they burn away very rapidly with a long flame. In the matter of burning, indeed, they exhibit all the qualities of the

fuliginous coals intensified. Some of the Derbyshire, South Staffordshire, and Scotch coals are of this character.

The elementary composition of the gaseous class may be represented as follows:

Carbon	75 to 80
Hydrogen	5·5 „ 4·5
Oxygen and Nitrogen	19·5 „ 15·5

Hence the ratio $\frac{O + N}{H}$ lies between 3 and 4. The specific gravity varies between 1·22 and 1·25.

Distillation gives:

Coke	50 to 60	
Ammoniacal Liquor	12 „ 5	Volatile matters, 50 to 40
Bitumen	18 „ 15	
Gas	20 „ 20	

The coke obtained from coals of this class is of a soft and pulverulent character, and useless for commercial purposes.

There exist certain varieties of coal which, though they do not possess all the qualities mentioned as pertaining to the gaseous coals, yet are of such a character that they must be ranged under that class. These are the important variety known as *Cannel;* those of the lignite family denominated *Brown coal;* and the mineral variety described as *Boghead cannel, Torbane Hill mineral,* and *Torbanite.*

"Cannel" is a very hard compact coal, of a black or brownish black colour, sometimes glossy, but more frequently dull in lustre. It does not soil the fingers when handled, and it is capable of taking a high polish. It breaks with a flat conchoidal fracture. Cannel is distinguished from ordinary coal by the absence of a laminated structure. This is a mark of its highest perfection, for when it becomes earthy and otherwise impure, the laminated structure is developed. In this state it is called "hoo-cannel" by the miners. It kindles very readily, and burns away in the hand with a very abundant white flame. It is from this quality that it derives its name of cannel, i. e. *candle* coal. It decrepitates much in burning, and from the rattling, chattering sound emitted it has received the name of "rattlers" in Yorkshire, and "parrot coal" in Scotland. Formerly cannel was much used as a source of mineral oil; but since the discovery of oil in America, it has been employed almost exclusively for gas making, for which purpose it commands a high price in the market. Seams of cannel occur in certain districts with ordinary coal, and often form the upper portion of a seam of bituminous coal, and occasionally of a bed of black-band ironstone.

"Brown coal," or "Lignite," is a term applied to all coals occurring in formations more recent than those of the Carbon Period. The processes of mineralization having been less completely effected in these later coals, they exhibit their vegetable structure more completely, and as an effect of the same cause, they retain a much larger proportion of volatile matters. In colour, they vary from brown to pitch black; their lustre is generally dull, but sometimes resinous; the fracture is various. They contain from 50 to 70 per cent. of carbon, and a much larger proportion of oxygen than the bituminous coals. They burn readily with a dull flame, emitting much smoke, and an unpleasant odour. In consequence of the small proportion of carbon and the large quantity of water which they contain, the brown coals do not possess great heating power. The deposits are more extensive on the continent of Europe than in England.

"Torbanite" or "Boghead mineral," is a highly bituminous shale occurring at Torbane Hill, in

Scotland, and is therefore of merely local importance. It is a brown substance, containing little more than 9 or 10 per cent. of carbon, with a very large proportion of ash. But the volatile matters are so abundant as to constitute from 60 to 70 per cent. of the whole, and hence the great value of this mineral as a source of gas, as much as 15,500 cubic feet having been extracted from a ton.

Local Names.—Almost every district has its own names to distinguish the numerous varieties of coal of every class. These names have, in most cases, reference to physical conditions. It is not desirable to give a list of them, as they have but little interest beyond the district in which they are applied. There are a few, however, more widely employed than the rest, which deserve special mention. "Stone coal," "crow coal," and "Kilkenny coal," are names applied to anthracite: the first having reference to the mineralized character of the coal; the second, to its iridescent hues, like those of the crow; and the last, which is used in Ireland, to the locality whence it is obtained. "Splint" is a Scotch term, and is applied to a hard variety of coal, capable of being cut in large blocks. It is of a dull lustre, not easily kindled, but when thoroughly lighted it burns brightly and is rather slowly consumed. It is largely used for steam purposes. "Cherry" is a soft and very beautiful variety, of a velvet-black colour, with a slight intermixture of grey. Its lustre is bright resinous; it is very tender, and its fracture is shaly. It kindles very readily, and burns away leaving but little ash. "Bone coal" and "spiry coal" are terms applied to hard varieties when the hardness is occasioned by the presence of clayey matters disseminated throughout the coal. Bony coal has a dull appearance, and leaves a very large proportion of ash after burning.

COMPOSITION OF COAL.—The vegetable origin of coal is, as previously stated, shown by its chemical composition, as well as by its structure and the remains which it contains. The essential elements of which it is composed are carbon, hydrogen, and oxygen, and the proportion in which these elements enter into the composition of the original wood, and the intermediate substances up to the ultimate product anthracite, show the process of change that has taken place. The formation of coal by the decomposition of woody tissue may be explained by the gradual elimination of hydrogen and carbon as carburetted hydrogen, of oxygen and carbon as carbonic anhydride, and of oxygen and hydrogen as water. The following table exhibits clearly the transformations that have been produced by the slow but continued action of chemical and other agencies, and the relation subsisting among the several classes of coal, and also between these and the vegetation of the present day.

Name of Substance.	Specific Gravity.	C	H	O + N
Wood—mean of 12 kinds	0·91	49·00	6·25	44·75
Peat—mean of 12 samples	0·99	59·30	6·52	34·18
Lignite—mean of 12 samples	1·25	72·37	5·18	23·45
Cannel Coal (Wigan)	1·27	80·07	5·53	13·50
Bituminous Coal—mean of the three divisions ..	1·30	86·17	5·21	8·62
Semi-Bituminous Coal—mean	1·37	91·00	4·75	5·25
Anthracitous Coal—mean	1·50	92·50	3·75	3·75

It appears from the foregoing table that the proportion of carbon, and, consequently, the specific gravity, increases, as previously stated, with the age of the coal. The large proportions of volatile matters present in the newer coals give them their flaming character, and constitute their value as gas producers. The calorific power of a coal depends mainly upon the excess of carbon which it contains, and hence the older coals possess the greatest value as heat producers. The figures in the

table give only mean values; in every class there are insensible gradations between the limits which have already been defined, and these variations occur not only from seam to seam, but in the different parts of the same seam. These mean values will, however, constitute a convenient term of comparison. The variations in the composition of coals of the same class are well exhibited in the following table, given in the 'Third Official Report on Coals suited to the Steam Navy.' The percentage of ash and that of the coke yielded by each variety are included in this table:

COMPOSITION OF VARIOUS BRITISH COALS.

Locality or Name of Coal.	Specific Gravity.	C	H	N	S	O	Ash.	Percentage of Coke left.
WELSH COALS:								
Aberamam Merthyr	1·305	90·94	4·28	1·21	1·18	0·94	1·45	85·0
Ebbw Vale	1·275	89·78	5·15	2·16	1·02	0·39	1·50	77·5
Thomas's Merthyr	1·30	90·12	4·33	1·00	0·85	2·02	1·68	86·53
Duffryn	1·326	88·26	4·66	1·45	1·77	0·60	3·26	84·3
Nixon's Merthyr	1·31	90·27	4·12	0·63	1·20	2·53	1·21	79·11
Binea	1·304	88·66	4·63	1·43	0·33	1·03	3·96	88·10
Bedwas	1·32	80·61	6·01	1·44	3·50	1·50	6·94	71·7
Hill's Plymouth Works	1·35	88·49	4·00	0·46	0·84	3·82	2·39	82·25
Aberdare Co.'s Merthyr	1·31	88·28	4·24	1·66	0·91	1·65	3·26	85·83
Gadly Nine-feet Seam	1·33	86·18	4·31	1·09	0·87	2·21	5·34	86·54
Resolven	1·32	79·33	4·75	1·38	5·07	{included in ash}	9·47	83·9
NEWCASTLE:								
Willington	..	86·81	4·96	1·05	0·88	5·22	1·08	72·19
Andrew's House, Tanfield ..	1·26	85·58	5·31	1·26	1·32	4·39	2·14	65·13
Bowden Close	..	84·92	4·53	0·96	0·65	6·66	2·28	69·69
Haswell Wallsend	1·286	83·47	6·68	1·42	0·06	8·17	0·20	62·70
Newcastle Hartley	1·29	81·81	5·50	1·28	1·69	2·58	7·14	64·61
Hedley's Hartley	1·31	80·26	5·28	1·16	1·78	2·40	9·12	72·31
Bates' West Hartley	1·25	80·61	5·26	1·52	1·85	6 51	4·25	..
West Hartley Main	1·264	81·85	5·29	1·69	1·13	7·53	2·51	59·20
Buddle's West Hartley	1·23	80·75	5·04	1·46	1·04	7·86	3·85	..
Hastings' Hartley	1·25	82·24	5·42	1·61	1·35	6·44	2·94	35·60
DERBYSHIRE:								
Earl Fitzwilliam's Elsecar ..	1·296	81·93	4·85	1·27	0·91	8·58	2·46	61·6
Hayland & Co.'s Elsecar	1·317	80·05	4·93	1·24	1·06	8·99	3·73	62·5
Earl Fitzwilliam's Park Gate ..	1·311	80·07	4·92	2·15	1·11	9·95	1·80	61·7
Butterly Co.'s Portland	1·301	80·41	4·65	1·59	0·86	11·26	1·23	60·9
Butterly Co.'s Langley	1·264	77·97	5·58	0·80	1·14	9·86	4·65	54·9
Stavely	1·27	79·85	4·84	1·23	0·72	10·96	2·40	57·86
Loscoe Soft	1·285	77·49	4·86	1·64	1·30	12·41	2·30	52·8
LANCASHIRE:								
Ince Hall Co.'s Arley	1·272	82·61	5·86	1·76	0·80	7·44	1·53	64·0
Haydock Little Delf	1·257	79·71	5·16	0·54	0·52	10·65	3·42	58·1
Balcarres Arley	1·26	83·54	5·24	0·98	1·05	5·87	3·32	62·89
Blackley Hurst	1·26	82·01	5·55	1·68	1·43	5·28	4·05	57·84
Ince Hall, Pemberton Yard ..	1·348	80·78	6·23	1·30	1·82	7·53	2·34	60·6
Haydock Rushy Park	1·323	77·65	5·53	0·50	1·73	10·91	3·68	59·4
Moss Hall, Pemberton Four-feet	1·258	75·53	4·82	2·05	3·04	7·98	6·58	55·7
SCOTCH:								
Wallsend Elgin	1·20	76·09	5·22	1·41	1·53	5·05	10·70	58·45
Wellewood	1·27	81·36	6·28	1·53	1·57	6·37	2·89	59·15
Dalkeith Coronation Seam ..	1·316	76·94	5·20	trace	0·38	14·37	3·11	53·5
Kilmarnock Skerrington	1·241	79·82	5·82	0·94	0·86	11·31	1·25	49·3
Fordel Splint	1·23	79·58	5·50	1·13	1·46	8·33	4·00	52·03
Grangemouth	1·29	79·85	5·28	1·35	1·42	8·58	3·52	56·6
Eglington	1·25	80·08	6·50	1·55	1·38	8·05	2·44	54·94
Dalkeith Jewel Seam	1·277	74·55	5·14	0·10	0·33	15·51	4·37	49·8

The calorific power of coal is largely influenced by the proportion of water and of inorganic matters which it contains. In the analyses made for the purposes mentioned in the Official Report referred to, it was ascertained that the mean proportion of water present in 24 examples experimented upon was 3·35 per cent. In some of the softer varieties the proportion is larger. The impurities are contained in the ash: the nature and the origin of these impurities have already been described and stated. When free from iron, the ash is white or light grey. The presence of iron colours the ash brown or red; and when the proportion is large, it causes the other constituents of the ash to fuse, and form clinkers. This quality often constitutes a serious objection to the use of coals containing iron.

Analyses of Coal.—The foregoing elementary analyses are very interesting and instructive. But proximate analyses are of more practical value, and can be far more easily made. It is a singular and highly suggestive fact that while, in Europe, reliance is almost exclusively placed upon elementary analysis, proximate analysis is as exclusively practised in the United States of America. The latter means enables us to determine readily the proportion of water and of ash present in any given specimen of coal, and the proportion which the volatile matters bear to the carbon. And this is all we require to know to enable us to ascertain the value of coal as a commercial commodity. The mode of conducting such an analysis will be clearly understood from the following descriptions.

Estimation of the Volatile Matters.—The only articles required in the operations are: a Bunsen gas burner; a blast gas burner, that is, an Argand gas burner with six jets, surmounted by a cylinder; a small covered platinum or porcelain crucible; a triangular support for the same; a sand-glass running exactly three and half minutes, and a sensitive balance.

The quantity of coal to be operated upon should be between one and two grammes, as this quantity gives constant results. The coal should not be dried previously to making the analysis, as the practice of some would authorize; for in that case we do not get the results which occur in practice. A small lump of coal might not give true results, because every block contains minute cubical portions differing considerably in quality from the mean of the whole mass. Portions of several lumps should therefore be procured, and reduced to powder in a mortar, and the requisite quantity taken from the mass after being carefully mixed to ensure a fair sample. When the portion to be operated upon has been placed in the crucible and weighed, the latter should be exposed to the constant flame of the Bunsen burner for three and half minutes, to obtain a red heat. At the expiration of this time it should be removed to the blast flame for another three minutes and a half, to obtain a white heat. The crucible with its contents should then be allowed to cool, after which it should be weighed again. The difference of weight represents the quantity of volatile matters removed, and this difference divided by the original weight will give the proportion, from which the percentage may be easily deduced. For example, if the weight of the pulverized coal before treatment was 1·50 grms., and after treatment 1·12 grms., the difference $1{\cdot}50 - 1{\cdot}12 = 0{\cdot}38$ grms. = the weight of the volatile matters driven off; and this divided by the original weight $\frac{\cdot 38}{1\cdot 50} = 0\cdot 25$, or one quarter, which is 25 per cent.

Estimation of the Moisture.—For the determination of the proportion of moisture present, there is needed a flat-bottomed iron pan, from 7 to 8 inches in diameter, supported upon an iron tripod. This pan is filled evenly to a depth of half an inch with sand, upon which is placed a thin copper plate. An iron arm, fixed at one end to a leg of the tripod by means of an indiarubber stopper,

carries at the other end a thermometer, so placed that its bulb is about $\frac{3}{16}$ inch above the copper plate. The coal, having been prepared in the manner and quantity already described, is placed in a watch-glass upon the plate, and a gas jet (preferably from a Bunsen burner) is applied beneath the iron pan, the thermometer being kept at about 105° C., or 220° Fahr. At the expiration of one hour the coal is removed, allowed to cool, and then re-weighed. The difference of weight represents the quantity of moisture evaporated, and the proportion is ascertained in the same way as that of the volatile matters.

Estimation of the Ash.—The determination of the quantity of ash yielded by any specimen of coal may be very easily effected. The coal is prepared in the same way and in the same quantity as in the foregoing cases, and burned in a platinum or porcelain crucible over a gas flame until the whole of the combustible matters are consumed. To promote rapid combustion, the crucible should be placed a little on one side, with its lid partially covering its mouth, so as to direct a current of air upon the burning substance. If the coal is of a highly caking quality, it is advantageous not to break the crust of the cake which is first formed, but to allow the mass to be gradually consumed from the outside. When coke is being operated upon, it is sometimes very difficult to consume the last portions of carbon. In such cases it may be necessary, in order to ensure rapid combustion, to direct a current of oxygen upon the burning mass at a red heat. This is effected by closing the porcelain crucible, when combustion becomes sluggish, with a cover having a hole through its centre, and inserting a suitable tube in communication with a gas-holder, the quantity of gas allowed to pass being regulated by a stop-cock. The residue constituting the ash, after being allowed to cool, is weighed, and the weight thus found, divided by that of the coal, will give the proportion of ash. The colour of the ash will indicate whether or not iron be present in sufficient quantity to have a notable influence upon the combustible.

Estimation of the Sulphur.—The determination of the quantity of sulphur contained by any specimen of coal presents greater difficulties than that of the volatile matters or the ash, and requires appliances and processes belonging more particularly to the laboratory. As, however, it is very frequently requisite to estimate the quantity of this substance, the following method is given as the most readily applicable: The coal to be operated upon is to be mixed with three times its weight of nitre, and four times its weight of pure carbonate of sodium, and the mass fused in a crucible. After cooling, this mass is to be first dissolved in hot water, and then filtered. Nitric or hydrochloric acid is next to be added to the filtrate to render it acid, which filtrate is then thrown down by barium-chloride. From the weight of the sulphate of barium thus obtained, the percentage amount of sulphur present in the coal may be deduced.

Determination of the Specific Gravity.—The method of determining the specific gravity has already been described in relation to rocks. The portion to be tested should be taken from the middle of a block of considerable size to ensure correct results. It is also important for practical purposes that the specific gravity found should be that of the coal with all its pores filled with water at a temperature of about 60° Fahr., the condition in which it comes from the pit. Suppose, for example, a piece of coal which has been exposed for a short time to a dry atmosphere shows a specific gravity of 1·31, and that the same piece after soaking in water shows 1·33. A cubic yard will weigh $1685{\cdot}34 \times 1{\cdot}31 = 2207{\cdot}80$ lb., and $1685{\cdot}34 \times 1{\cdot}33 = 2241{\cdot}50$ lb. respectively; that is, there would be a difference of 33·7 lb. in the cubic yard. To obtain correct results, therefore, the coal should be previously soaked for twelve hours in water of about 60° temperature.

Besides ascertaining the percentage of the constituent elements, it is often desirable, for the purpose of forming a proper comparative estimate of the character of the coal, to reduce the composition to a form in which the proportions of the volatile matters and the ash may be compared with that of the carbon represented as a constant quantity. For example, we found in one of the foregoing analyses that the proportion of volatile matters was 25 per cent. That is, to 75 parts of carbon there were 25 parts of volatile matters. If we wish to represent the carbon as a fixed quantity = 100; in other words, if we wish to know how many parts of volatile matters there are to every 100 parts of carbon, we may state the composition as 100 carbon and 33 volatile matters.

When the burners mentioned in the foregoing paragraphs are not easily obtainable, the blowpipe may be used. The cover of the crucible should be left very slightly open, to afford easy escape for the gas, but not sufficient to allow any of the solid matters to fly off. The heat should be increased to redness, and kept up until the escaping gases cease to burn. It may be remarked here that a quick heat will give less coke than a slow heat by several per cent.; but it will often make a dry coal cake that would not cake at all with a slow heat. In all cases where accuracy is important, experiments such as the foregoing should be repeated at least twice, and a mean taken.

Calorific Power of Coal.—In order to estimate the relative amount of heat evolved in the combustion of the various kinds of fuel, it is necessary to assume some standard of comparison; and as heat cannot be directly measured, this standard must have reference to the effects which heat produces. Various methods of estimating such effects have been devised. One, adopted by the British Admiralty Commissioners, in 1848, was to measure the quantity of heat by the weight of water at 212° Fahr., that it was capable of converting into steam of the same temperature. This and other methods have been abandoned in favour of what is known as the continental and British *units of heat*. The former is the quantity of heat required to raise 1 gramme of water from 0° to 1° C.; the latter the quantity required to raise 1 lb. of water from 32° to 33° Fahr. As the former has reference to the only thermometer constructed upon a rational basis, and as, moreover, it is being gradually adopted in England, while being almost universally employed abroad, the following remarks will have reference to it. In this standard of comparison, all that is assumed is, that if a certain quantity of heat produce a given effect upon a given quantity of water, then to produce the same effect upon another similar quantity of water, the same quantity of heat will be required; that is, in other words, to produce the same effect, twice the quantity of water will require twice the quantity of heat, and so on.

The calorific power of a fuel, therefore, may be expressed in units of heat; and the number of such units evolved during the combustion of 1 gramme of the substance is taken to represent its calorific power. Numerous experiments, carefully conducted and reduced to a mean value, have shown that the calorific power of pure carbon, that is, pure as obtained in practice in the form of purified wood-charcoal, is 8080, and that of hydrogen 34,462; hence we are able to calculate the calorific power of any fuel when we know its elementary composition. The calorific powers of the foregoing substances corresponding to the British unit of heat, determined for the pound weight, are 14,500 and 62,032 respectively.

To estimate the calorific power of coal, the following formula was proposed by Dulong:

$$P = 8080\,C + 34462\left(H - \frac{O}{8}\right),$$

in which P represents the calorific power, C the weight of carbon, and $\left(H - \frac{O}{8}\right)$ the weight of *free* hydrogen; that is, the total quantity of hydrogen less that which would be taken up by the oxygen contained in the coal to form water. This formula has been, and still is, largely employed in determining the relative values of different varieties of coal. But as it does not take sufficient account of the chemical effects of combustion as influenced by molecular constitution and other conditions, it must be considered as giving only roughly approximate results. Carbon develops 2473 units of heat in being converted into carbonic oxide, and the latter gas develops $8080 - 2473 = 5607$ units of heat by combining with a new equivalent of oxygen, to form carbonic acid. Hence, apparently, equal quantities of oxygen develop very unequal quantities of heat. But, in the former case, the *solid* carbon passes into the gaseous state, while, in the latter case, carbon already in the gaseous state is being burned.

If now we admit that Welther's law holds true so long as the chemical reactions are neither accompanied nor followed by a change of state, we see that the excess of 5607 over 2473, or 3134 units of heat must correspond exactly to the heat absorbed by the conversion of the carbon into gas. Consequently, carbon *in a gaseous state* would develop $8080 + 3134 = 11{,}214$ units of heat, if it gave carbonic acid directly. Reasoning from these facts, M. Grüner concludes that when applied to the carbon contained in coal, some value nearer 11,214 than 8080 is should be adopted, and suggests 9000 as an appropriate value. In like manner he would substitute the calorific power of hydrogen in a *solid* state for that of *gaseous* hydrogen, and gives 30,000 instead of 34,462 as the value required. The formula as thus modified would be, $P = 9000\,C + 30{,}000\left(H - \frac{O}{8}\right)$, and the results given by it are much nearer the truth than when it is in its original form. Even when thus modified, however, the values obtained by it are too low for the anthracitous coals, and too high for those of the richer varieties of the bituminous class. Such a formula can at the best be only approximative; but when only the elementary composition of a coal is known, it may be useful in determining the relative value.

A fatal objection, however, to any formula founded upon the elementary composition of coal, lies in the inability of elementary analysis to reveal the actual properties of the coal. Specimens nearly identical in their composition may differ widely in their calorific power. Grüner gives an example of coals from Le Creuzot and Ronchamp, the composition of the former being C 88·48, H 4·41, O 7·11, and that of the latter C 88·32, H 4·78, O 6·89. Yet the calorific value of the former was 9622, while that of the latter was only 9077; and the former yielded only 19·6 per cent. of volatile matters, while the latter yielded 27 per cent. The Ronchamp coal gives off, when distilled, a larger portion of carbon to the hydrogen and oxygen; and hence it is evident that in that example the union of the gases with the carbon is more intimate than in that from Le Creuzot, and hence also a larger amount of heat is given off and lost. The larger the proportion of volatile matters present, the lower is the calorific power of the coal. That the calorific power varies as the proportion of fixed carbon left after distillation is shown, not only by the foregoing example, but by numerous others adduced by MM. Scheurer, Kestner and Meunier, Favre, and Silbermann, and other eminent chemists. It should, however, be remarked, that the proportion of coke decreases somewhat more rapidly than the calorific power. Thus the proximate analysis will reveal not only the proportions of the coke, the volatile matters, the ash, &c., but also the calorific power, with a much closer

approximation to the truth, and in a far easier manner, than the elementary analysis aided by doubtful formulæ.

Experiments, carried out under conditions that obtain in practice, have shown the mean evaporative powers of the several classes of coal to be as follows (the evaporative power is the weight of water which 1 lb. of coal is capable of evaporating from 212° Fahr.):

Gaseous Class		6·25 lb.
Bituminous Class	Fuliginous Division	8·00 „
	Flaming Division	8·75 „
	Clear-burning Division	9·25 „
Semi-Bituminous Class		9·10 „
Anthracitous Class		9·20 „

Uses of the different Qualities of Coal.—It has been shown that coal varies greatly in quality, both in relation to its composition and its physical properties. Hence it is obvious that some kinds are more suitable for certain uses than others, and that the value of each kind can be taken advantage of only by applying it to that use to which its qualities specially adapt it. This is important to the mining engineer and the colliery proprietor from a commercial point of view, for the selection of a wrong market will certainly entail pecuniary loss. It now remains, therefore, to point out very briefly the qualities of coal that are required in the principal uses to which that mineral is applied.

Coal for Metallurgical Purposes.—The enormous consumption of coal required in the manufacture of iron renders this by much the most important metallurgical undertaking, from the coal producer's point of view; and it is the only one to which the following remarks will have reference. A primary condition which any kind of coal must fulfil to render it fit for employment in iron manufacture, whatever its qualities may be in other respects, is that it shall be free from sulphur. The presence of sulphur in iron is very deleterious to its quality, producing that state of its constituted particles which is technically known as "red shortness." Hence the fuel employed in its manufacture must not be capable of communicating this substance to it. It is mainly for this reason that wood charcoal is employed when iron of an unusually tough character is required. All coals contain sulphur: the purest from one half to one per cent.; the most impure, three and even more per cent. When the proportion exceeds one and a half per cent., the coal becomes unfit in its raw state for metallurgical purposes. Thus the visible presence of iron pyrites will at once show the unsuitable character of the coal.

When a given specimen of coal has been proved to fulfil this primary condition of freedom from sulphur, it remains to test its other qualities which may render it a good metallurgical coal. The calorific power of a coal is, as we have shown, proportional to the amount of carbon it contains. The proportion of ash represents so much loss of heat, besides the inconvenience which the presence of such matters occasions. A greater loss is due to the quantity of water present, for not only does the water occasion a negative loss proportionate to its amount, but a positive loss equal in amount to the quantity of heat abstracted to evaporate the water. Thus a large proportion either of ash or of moisture, or of both, tends to render a coal unsuitable. In metallurgical operations, intense local heat is required, and hence the coal employed must contain a very large proportion of carbon. This condition excludes the flaming and the fuliginous varieties of the bituminous and those of the gaseous classes altogether in their raw state. The anthracitous and the semi-bituminous classes, therefore,

with the clear-burning varieties of the bituminous class, can alone be considered applicable to this use. The two former classes also possess two other qualities which are required in the blast and refining furnaces, but which are not found in bituminous coal, namely, strength and freedom from a liability to cake. The great weight of the charge would crush a tender coal to powder, and an agglomeration of the mass would seriously impede the draught. The variety which best fulfils all these conditions is anthracite; but it possesses defects which go far to render it unsuitable. Though very strong naturally, it may be reduced by decrepitation in the furnace to the state to which the weakest is brought by pressure. It moreover requires, on account of its difficult combustion, a high-pressure hot blast, and a special construction of the furnace, to avoid a slow descent of the charges, and a consequent loss in the quantity of metal produced. In consequence of these defects, anthracite is not largely employed where more suitable varieties are easily procurable. Such varieties are those of the anthracitous and many of the semi-bituminous classes.

The defects possessed by coals of the bituminous class may be removed by coking. This process expels the volatile matters and leaves as a residue the carbon and the ash. In this state, that is, when converted into coke, provided the conditions of freedom from sulphur and a large proportion of ash be fulfilled, clear-burning coals of the bituminous class are more suitable for metallurgical purposes than those of the anthracitous and semi-bituminous classes, and they are very largely employed. In coke, the carbon attains its maximum proportions, and the hardness and the strength of the combustible their maximum degree. Another advantage of converting bituminous coal into coke is, that it allows the small coal, which as such is nearly worthless, to be utilized. Coals of this class do not all coke with equal readiness, nor is the coke obtained from them of equal quality. Some varieties require a quick heat to produce the best results, while others will not coke at all after some days' exposure to the atmosphere. These peculiarities demand careful attention. One important gain from the process of coking consists in the removal of a portion of the sulphur present, thereby enabling a coal to be utilized for metallurgical purposes that would otherwise be unfit for that use. Coke, to be suitable for the smelting furnace, besides freedom from sulphur and ash, must possess the qualities of hardness, compactness, and strength to withstand considerable crushing force: that which is brittle or liable to crumble is useless for the purpose. It is also of little value unless it can be obtained in large prismatic pieces. Hence good coke should, on cooling, split into such pieces, somewhat in the manner of columnar basalt. Its colour should be steel grey, almost approaching to a silvery whiteness. An iridescent hue indicates the presence of sulphur. When struck, it should emit a clear and almost metallic ring. Frequently a large proportion of moisture is imparted to coke by the thoughtless way in which the extinction is conducted by the burners. By the application of large quantities of water, evils are entailed of the first magnitude in the economical working of the smelting furnace.

In the calcining of iron ores small coal is employed, and the same is sometimes used in the puddling furnace: in such cases the quality of strength is of less importance.

The coals best suited for forging purposes are the richest of the clear-burning varieties of the bituminous class. Their property of caking is an advantage, by allowing the formation of cavities, or, in the language of the trade, a "hollow fire." The portions of coal cohere into a compact mass on the outside of the fire, so as to form a covering within which the heat is confined. This covering not only intensifies the heat at the point where it is most required, namely, upon the iron to be forged, but it very effectively shields the workmen from it, which, in hot weather especially, is an

important advantage. Such a fire is, moreover, more economical than an open one. Coals of this quality are usually of a beautiful black colour, with a bright, fatty lustre. They are tender, and break into small cubical fragments. The absence of sulphur is an indispensable condition in forge coal for reasons already stated, and therefore pyritous, or "red-ash," coal is altogether unsuitable. The presence of a large proportion of earthy matters is very objectionable; for not only is a loss of heat occasioned thereby, but they are apt to stick to the heated iron, and so constitute a source of danger and of irritation to the workmen.

Coal for Steam Purposes.—Next to metallurgical purposes, the generation of steam constitutes the most important use to which coal is applied. The qualities requisite in a steam coal are, in the main, identical with those which render a coal suitable for the smelting furnace, though an intense local heat is not so desirable for the one purpose as for the other. The absence of a large proportion of ash and of water is, of course, an essential condition in a good steam coal, and freedom from sulphur is of primary importance. Yet a slightly larger proportion of the latter substance may be allowed than when the combustible is applied to iron manufacture. The coal should be strong, to withstand rough usage, as otherwise there will be a considerable loss from the small pieces falling through the bars of the grate. Moreover, an accumulation of small coal upon the bars impedes the draught. A similar reason precludes the use of caking coals, except under certain conditions. Their tendency to agglomerate into a fused mass necessitates much intelligent attention, and if this is obtainable, such coals may frequently be used with advantage. But otherwise, they are unsuitable for the purpose, and hence are not largely employed. The free-burning varieties of the anthracitous and semi-bituminous classes unite most of the requirements of a good steam coal adapted to the conditions of practice. Anthracite is objectionable by reason of its difficult combustion, its tendency to decrepitate while burning, and the close attention it requires on the part of the fireman. Also the intense local heat which it develops rapidly destroys the fire-bars. Hence it is but sparingly used as a steam coal wherever other varieties are readily obtainable. Of these numerous varieties each possesses qualities which render it preferable under given conditions. For example, the lively burning coals of the semi-bituminous class, and the poorer varieties of the clear-burning coals of the bituminous class, are peculiarly suitable for the quick generation of steam. Much may often be gained by a judicious admixture of two varieties, or of two classes, the compound in such a case possessing qualities which neither of the constituents have separately. Bituminous coal may often, without skilled attention, be advantageously employed in this way.

A very large proportion of the steam coal raised is burned at sea, under conditions somewhat different from those prevailing on land. The same qualities of coal are needed; but some of these qualities must exist in a higher degree. The rough usage which coal must necessarily be subjected to before it reaches the fire-grates requires great strength; and the limited space available for storage demands a high specific gravity combined with a high evaporative power. The following conditions were laid down as necessary in coal for use at sea by the Commissioners appointed by the Admiralty to inquire into the merits of the several kinds of steam coal in use in the Royal Navy:

"1. The coal should burn so that steam may be raised in a short period, if this is desired; in other words, it should be able to produce a quick action.

"2. It should possess high evaporative power, that is, be capable of converting much water into steam, with a small consumption of coal.

"3. It should not be bituminous, lest so much smoke be generated as to betray the position of ships of war when it is desirable that this should be concealed.

"4. It should possess considerable cohesion of its particles, so that it may not be broken into too small fragments by the constant attrition which it may experience in the vessel.

"5. It should combine a considerable density with such mechanical structure that it may easily be stowed away in small space; a condition which, in coals of equal evaporative values, often involves a difference of more than 20 per cent.

"6. It should be free from any considerable quantity of sulphur, and should not progressively decay, both of which circumstances render it liable to spontaneous combustion.

"It never happens," they say, "that all these conditions are united in one coal. To take an instance: anthracite has very high evaporative power, but not being easily ignited, is not suited for quick action; it has great cohesion in its particles, and is not easily broken up by attrition, but it is not a caking coal, and therefore would not cohere in the furnace when the ship rolled in a gale of wind; it emits no smoke, but from the intensity of its combustion causes the iron of the bars and boilers to oxidate or waste away rapidly. Thus, then, with some pre-eminent advantages, it has disadvantages which, under ordinary circumstances, preclude its use. The conditions above alluded to may, however, often be united in fuels artificially prepared from coals possessing these various qualities."

Coal for Gas Purposes.—The manufacture of gas for lighting purposes constitutes one of the chief uses to which coal is applied. And as the qualities demanded are different from those required for other purposes, this application of coal is of peculiar importance to the producer. The first essential condition which a coal must satisfy to render it suitable for gas making is, that it shall possess a large proportion of hydrogen; and hence, other things being equal, the value of a gas coal will be proportionate to the quantity of that constituent. This condition is most fully satisfied by the flaming and fuliginous varieties of the bituminous and gaseous classes; and of the latter, torbanite and cannel possess the requisite qualities in the highest degree. The former will yield from 14,000 to 15,000 cubic feet of gas a ton, of an illuminating power equal to thirty-four sperm candles. But as this mineral is found developed only in one locality, and that locality is now nearly exhausted, commercially it is of small importance. The yield of cannel is from 9000 to 10,000 cubic feet of gas a ton, of about twenty-four candle illuminating power. On account of the quality of the gas yielded, this variety is much sought after by the manufacturers, who employ it to increase the illuminating power of the gas produced from coals of an inferior class, and hence it commands a high price in the market. But though the production of gas is the primary object of the gas-maker, another very important consideration presents itself to his notice, namely, the utilization of the residual products. The chief of these is coke, which is the residue of the coal after the volatile matters have been abstracted. As fuel is required in the process of gas making, a portion of this residue may be employed for that purpose, and the remainder sold for uses in which coke of the highest quality is not needed. Thus a good coking coal may be equal in value to another of superior gas-producing, but inferior coking qualities. And, if we except cannel, it may be laid down as a necessary condition that a good gas coal must also be a fairly good coking coal. Cannel yields coke of a very inferior quality; but the extraordinary quality of its gas more than compensates this defect. With this exception, the requirements of a gas coal are best fulfilled by the richer varieties of the bituminous class. These yield from 8000 to 10,000 cubic feet of gas a ton, of an illuminating power varying

from ten to twelve sperm candles. Generally, the greater the quantity of gas obtained, the higher will be the illuminating power. A fortunate circumstance to the coal producer is that strength is not an essential condition in a coal to be used for the manufacture of gas, as it is in those employed for metallurgical and steam purposes; and hence the tender varieties may be applied to this use, and a market is obtained for the smaller portions which otherwise might not be saleable. It should be remarked that freedom from sulphur is requisite in this as in the other uses which have been described. Indeed, it may be said that the presence of this substance, in any but very small proportions, unfits a coal for every purpose.

Coal for Domestic Use.—A large proportion of the coal raised is consumed in heating the atmosphere of dwellings, and other domestic purposes; and as this use affects, in a greater or less degree, every member of the community, it constitutes from more than one point of view one of the most important to which coal is applied. The qualities required in a good house-coal are numerous, and such as are rarely found united and fully developed in one variety. An essential condition is that it shall be clean in itself, and clean in burning. The former quality necessitates a considerable degree of strength to prevent crumbling, and the consequent production of dust; and the latter requires comparative freedom from earthy impurities. A coal that leaves a large amount of ash is highly objectionable. There is in some parts, especially in London, a prejudice against coals leaving a white ash, even when the proportion is small, due probably to the conspicuous character of the ash. On the other hand, the red-ash coals are liable, when the proportion of ash is large, to fuse and form clinkers on the bars. Coals that are to be consumed in domestic fireplaces of the ordinary construction, must be capable of burning with a light draught, and with a bright, lively flame, the cheerful character of the fire, so much desired, depending mainly upon the latter quality. The coals in which most of these qualities are found united are the flaming varieties of the bituminous class; and these are exclusively employed wherever they can be readily obtained. In the United States of America, where until very recently bituminous coal was not easily procurable, anthracite, as before stated, is generally employed. This coal is, however, very far from fulfilling the conditions, considered essential in England, of burning with a light draught and with a cheerful flame. The caking quality of bituminous coal is an advantage in ordinary fireplaces, by occasioning the formation of a cake or "mat" at the top of the fire, whereby the upward flow of the heated gases is impeded, and the heat caused to radiate more into the room. This "mat," however, requires to be broken occasionally, or the impediment to the draught will become so great as to prevent combustion. This tendency to mat, which is an advantage in a sitting-room with an open fire, renders caking coals unsuitable for the kitchen, where the heat is needed for cooking purposes, and where frequent stirring is undesirable; and for use in stoves to which constant attention cannot be given. For these purposes, coals of the semi-bituminous class are used, either alone, or mixed with the small of the bituminous class.

Besides the foregoing uses to which coal is applied, it may be desirable to mention its employments in kilns of various kinds, for which purpose the anthracitous varieties are generally the most suitable.

Produce of Coal Seams.—When the thickness of a seam of coal is known, its yield per acre may be readily calculated. In determining the thickness of a seam, care must be taken to deduct that of dirt partings or of any inferior layers of coal that may exist, as a calculation of the produce founded upon the total thickness, irrespective of the quality, might prove utterly delusive. Also, in some cases, it is necessary to leave a portion of the coal to form the roof, when, of course, such

portions will have to be deducted. By the thickness of a seam, as determined for purposes of calculation, is understood the total available thickness of marketable coal. When this thickness has been ascertained, the produce of a seam may be estimated in the following manner. Taking the average specific gravity of gaseous coal as $1 \cdot 24$, a cubic foot will weigh $1 \cdot 24 \times 62 \cdot 4 = 77 \cdot 37$ lb.; hence a square yard one foot thick will weigh $77 \cdot 37 \times 9 = 696 \cdot 33$ lb.; and an acre of the same thickness, $696 \cdot 33 \times 4840 = 3{,}370{,}092$ lb. = 1505 tons. Thus for every foot in thickness, a seam of coal of this character contains 1505 tons an acre. When a seam is inclined at a considerable angle, an acre of surface, assumed to be horizontal, will cover more than an acre of the seam, and in such a case the necessary correction for inclined measure must be made. In the same way it may be shown that bituminous coal, having a mean specific gravity of $1 \cdot 30$, will yield 1577 tons; semi-bituminous coal, with a specific gravity of $1 \cdot 37$, 1662 tons; and anthracitous coal, with a specific gravity of $1 \cdot 50$, 1820 tons an acre. As an example, suppose a seam of bituminous coal, 5 feet thick, of which 3 feet 9 inches = $3 \cdot 75$ feet is of marketable value; the total yield of such a seam will be $1577 \times 3 \cdot 75 = 5914$ tons an acre. But as there will always be a certain proportion of coal lost, either in pillars or in other situations, this proportion must be deducted from the total to obtain the actual yield. What this proportion will be will depend upon the system of working and the particular conditions of the case, and can therefore be determined only by experience. Also, when it is known what proportions of large and small coal a seam makes under given conditions of working, the actual yield may be divided according to those proportions, and its value accurately estimated.

Coal, like rock, when removed from its natural position in the bed and broken up, increases greatly in bulk. This increase is an important element in the question of production with reference to labour and time; in other words, the daily output. For it will determine the duration of a given portion of the seam relatively to the number of tub loads extracted daily, and the number of loads which a given working face will yield for every three feet in depth, that is, at every "holing." The actual amount of the increase in bulk varies with the character of the coal, so that only an approximate value can be assigned to it. But the approximation will be sufficiently close if we take the mean value as 60 per cent.; that is, a cubic yard of coal will, when broken up, occupy a space equal to $1 \cdot 60$ cubic yards, or $43 \cdot 2$ cubic feet. Hence if the tubs used be 3 feet 6 inches in length, 2 feet 9 inches in depth, and 2 feet 6 inches in mean width, which dimensions will give a capacity of $3 \cdot 50 \times 2 \cdot 75 \times 2 \cdot 50 = 24$ cubic feet, one cubic yard of coal will require for its transport to bank $\frac{43 \cdot 2}{24} = 1 \cdot 8$ tubs, or 5 yards will require 9 tubs.

Comparative Value of large and small Coal.—Coal is greatly deteriorated in value by being broken up into small fragments. Hence this matter of the *condition* of coal is one that will enter largely into the economy of mining, and constitutes, therefore, an important element in the success of every undertaking. And it is for this reason that the practical ability of an underground manager is, as we shall subsequently show, judged, to a very great extent, by the proportion of large coal that he is able to send to surface. The question of profit is mainly dependent upon three circumstances: first, the character of the coal; second, the cost of production; and third, the condition in which the coal is delivered. It has already been shown that the first of these circumstances determines the suitability of a coal for any given use, and therefore its market. The character of the coal, which will largely influence the price obtained, is, however, beyond the control of the engineer. The other circumstances, namely, the cost of production and the condition of the

coal, he may modify to a considerable extent. But it must be borne in mind that however the cost of production may be modified, it will remain the same for all conditions of the coal; that is, a ton of the worst quality will have cost as much by the time it is delivered at surface as a ton of the best quality. Thus it is obvious that the circumstance of the condition of the produce demands special attention, as, if unfavourable, it may nullify the advantages obtained from the others.

The relative values of the several sizes into which the coal is broken during the process of extraction may be shown in a convenient tabular form as follows:

Best Coal	= 1·000	= say 1*l.*
Seconds	= 0·900	= „ 18*s.*
Thirds	= 0·825	= „ 16*s.* 6*d.*
Slack	= 0·450	= „ 9*s.*
Smudge	= 0·240	= „ 4*s.* 9*d.*

The *best* consists of all large pieces; the *seconds* consists of smaller pieces, but with the slack taken out; the *thirds* is the coal as it comes from the pit, with the large and small mingled, the small in this case being assumed to form an average proportion of the whole; the *slack* is the portion which has passed through a screen having a mesh of $1\frac{1}{2}$ inch; and the *smudge* that which has passed through a screen the meshes of which are $\frac{1}{4}$ inch only.

A glance at the foregoing table will show the value of the physical condition of strength in the coal, and the necessity for careful attention in laying out and directing the workings.

CHAPTER III.

SEARCHING FOR COAL.

Preliminary Considerations.—Before commencing an active search for seams of coal in a district where their presence is suspected, certain questions of paramount importance which present themselves for immediate consideration must be indisputably and favourably solved. An essential condition of existence in every undertaking of a commercial character is, that it shall "pay." Profit is the object and end of every kind of industry, and if this end be not attained, the industry must cease. All readily enough acknowledge this fact, and yet, strange though it may seem, great undertakings, and especially great mining undertakings, are frequently entered upon without having first clearly determined the satisfactory fulfilment of this necessary condition. It is evident that the question cannot be finally decided in the affirmative until all the important circumstances of the case are known; and these can be ascertained only by careful and extensive explorations judiciously devised and skilfully executed, aided by patient inquiry, and guided by an unbiassed judgment. But if certain clearly apparent circumstances exist which are sufficient of themselves to show that the undertaking cannot be commercially successful, even if all the other circumstances should prove favourable, it is plain to ordinary common sense that it would be sheer folly to prosecute a search which must necessarily be an expensive one, and which must as necessarily end in disappointment. Enormous sums of money have been expended in this way to the great and manifest injury of all legitimate enterprise. The preliminary questions which present themselves for solution may be classed under two heads, as general engineering questions, and general commercial questions, the latter being greatly dependent on the former.

General Engineering Questions.—A primary question which the engineer will have to take into consideration is that of labour. Is hand-labour abundantly available, or is it otherwise? The value of labour, like that of every other merchantable commodity, is determined by the demand and the supply, and therefore varies inversely as the abundance of the supply. A scarcity of labour may arise from several causes: one cause is the sparseness of the population. In such a case, the engineer will have either to restrict his output to the capabilities of the available resident population, or to import labour from other localities. If he is compelled to adopt the latter alternative, the cost of the labour must necessarily be high. For though he may obtain his workmen from localities where, in consequence of the supply being greatly in excess of the demand, the rate of wages is low, he will have to offer a considerable premium to induce them to migrate; and this premium must be large in proportion to the distance and the unattractive character of the new settlement. Moreover, the same rate of payment will in a short time be demanded by the natives, so that the maximum rate will have to be taken as the basis of calculation. In some localities the population may be numerous,

but there may exist on the part of the inhabitants a strong dislike for the work of the miner. This is not unfrequently the case where the natives gain a comparatively easy livelihood by agricultural pursuits. In such cases, not only is it necessary to combat the prejudice by the offer of a high premium, but a large proportion of the labour required will, at least in the first instance, have to be imported. Similar conditions exist where, in perhaps a densely populated district, other large industries are carried on. Here, again, the workmen will have to be tempted by the offer of higher wages to relinquish their former occupation for that of mining. When estimating this cost of labour, the engineer must bear constantly in mind that the creation of a new and important industry, like that of mining, must necessarily tend to constantly raise the value of labour in that district, by the increased demand occasioned by the extension of that industry.

Next to the cost of labour, the cost of materials must be estimated. In a country where timber is plentiful, the cost may remain low for many years, notwithstanding the increased demand for it. But even in this case the value must tend gradually to rise. When, however, it becomes necessary to import timber from a great distance, its cost will constitute an important item in that of production. The other materials required will vary in cost according to the facility with which they may be obtained.

Another matter claiming serious consideration is the means afforded by the locality for the conveyance of the produce to points where it may be disposed of. A mountainous district may offer insuperable obstacles. In some localities, practicable means of conveyance may be devised; but the labour of constructing roads or short lines of railway may entail enormous expense. Frequently, where lines of railway are needed, it will be prudent to wait till other parties are found to take up the question of conveyance, before commencing the opening out of a new field. But whether the difficulties presented be great or small, this question of transport is an exceedingly important one, influencing in no inconsiderable degree, not only the present, but the future success of the undertaking, and demanding, on the part of the engineer, knowledge, skill, and prudence.

General Commercial Questions.—Founded mainly upon the foregoing, there exist certain other questions of an entirely commercial character, demanding careful consideration. The first is, the cost of production at the pit's mouth. In estimating this, the conditions of working may be assumed to be of an average character, and a comparison made with the district from which the present supply is obtained. Suppose, for example, that the cost of production at the pit's mouth in this district is 5*s.* a ton. If it can be shown that labour, after the premium for its attraction, previously described, has been allowed for, can be obtained for 20 per cent. less cost in the new district, as this constitutes by much the most important item in the total cost of production, we should not be far wrong in assuming that cost to be 20 per cent. less, or 4*s.* 6*d.* per ton. In like manner, if the cost of labour were 20 per cent. more, the cost of production in the new district would be 5*s.* 6*d.* a ton. Whenever a great difference exists in the cost of materials, this difference must, of course, also be taken into consideration. By these means, the value of the coal when raised to surface may be approximatively determined; but this value is of itself not sufficient to indicate the price at which the produce of a colliery may be sold to obtain a given profit. This question may be involved in the next which we have to consider, namely, the *market* for the produce.

By the term "market" is understood the geographical area over which the produce may be profitably distributed. The extent of this area will evidently depend upon several conditions. The natural market of any given district is included within a radius from the centre of production of

such a length that the produce may be delivered at its extremity at the same price as that demanded by the competing districts. To make this clear, suppose a district, C, supplied with coal from two other districts, A and B, situate on opposite sides of C, and at equal distances from the centre of the latter. If A is placed in more favourable conditions of working than B, its produce will be raised at a cheaper rate; and if, in addition to this, it is more favourably situate with respect to C in the matter of conveyance than B is, it is plain that A's market will extend beyond the centre of C, because it can deliver its produce at that point at a lower price than B can. And the boundary of the two markets may be shown on the map by a line drawn through those points at which the two districts deliver their produce at the lowest possible price consistent with a reasonably remunerative profit. If the facilities for transport were equal in all directions, such boundary lines would be circles tangent at the point at which they cut a straight line joining their centres. But as this equality never exists, the boundary will be an irregular, and frequently a very irregular, line. Suppose, again, that coal is discovered in the centre of the C district; the question is, What will be the boundary of C's market? Evidently the whole of this market will be taken from A and B; but in what proportions? Assuming the cost of production in C to be the same as in A, it is clear that the latter's boundary will be driven farther back than B's, because of the greater facilities of transport that exist between A and C than between B and C; and also that the boundary line of the latter in the direction of A will be midway between the centres of production of C and A. In the opposite direction towards B, C's boundary line will extend beyond the midway point by a distance which will be proportionate to the difference in the cost of production in C and B. In all of these considerations it is assumed that the quality of the produce is the same in all the districts. Variations of quality, however, except in special circumstances, may be considered as variations in cost, a deterioration in quality being equivalent to a proportionate increase of the cost of production.

It will be evident on reflection that the consumption of the produce within the area comprising a market will be much greater in some points than in others. Great industries, populous towns, or important seaports, may exist, which may occasion a very large demand within a limited area. Whence it follows that a very small market, geographically, may be of far greater importance than one of much wider extent. But it is equally evident that the larger the market is geographically, the greater is the chance of its increasing in importance by the growth of new industries, and the development of the districts included within it.

It follows from the foregoing considerations, that the conditions which determine the extent of the market are, first, the cost of production; and, second, the facilities which exist or may be created for transport. In general, the latter condition will be the more important; and in taking it into account, future contingencies must be kept clearly in view. A district which, for example, is imperfectly served by a railway now, may by its development attract fresh capital towards the extension of the system, or the construction of new and competing lines. And the same remark is applicable, with a change of terms, to a service of shipping from a seaport, or other means of transport.

Thus, in considering the commercial questions affecting a new district, it may be ascertained that the market for the produce would be too limited in extent to justify the employment of a large capital in an undertaking of a somewhat hazardous nature. Or it may be, that in consequence of the absence of any means of transport, and the existence of insuperable natural obstacles to the creation

of any such means, there can be no market at all. Or, again, a wide market may exist; but in consequence of the absence of large industries, a numerous population, or seaports, or the possession of an abundant supply of wood, it is at present valueless. If any one of these circumstances should be proved to exist, it would be folly to undertake an expensive search for coal, and prudence will dictate the abandonment of the scheme at this stage, or at least its postponement until the progress of events shall have changed the existing condition of things. But if, on the other hand, it be indubitably proved that no one of these circumstances can occur, then we have ample justification for entering upon the search, and prosecuting it with vigour. And here we may venture the remark, that when once the preliminary considerations have been determined favourably, neither time nor expense should be spared in bringing the search to a satisfactory issue. If it is folly to begin before having carefully considered the commercial aspects of the question, it is still greater folly to prosecute the search in such a way that the problem cannot be finally solved thereby, or to cease before that end has been attained.

Determination of the Existence of Seams of Coal.—The determination of the existence of coal seams in any given locality, whether that locality be a wholly new and unknown one, or bordering upon another in which seams are known to exist, is a labour of a purely geological character. And the knowledge to be applied in such investigations must be wide and general. That which is obtained by experience in the mine, and which may be described as local and particular, is totally insufficient for the purpose. An acquaintance with the broad facts of geology, as well as a familiarity with local phenomena, are absolutely indispensable. And these must be supplemented by accurate mineralogical knowledge, upon which the truth of geological inferences often greatly depend. Possessed of such knowledge, the explorer is able to prosecute the search for coal in a rational and systematic manner, that must infallibly lead to certain results. The mode of conducting the search in a wholly new locality will vary somewhat in detail from that observed in a partially known district.

Searching in a New Locality.—A search for coal in a new locality should consist of two stages, which may be described as the "general," and the "particular." The first, or general stage of the search, will be devoted to the making of a geological survey of the district, in the manner described in the first chapter of this work. As the object of this survey is rather to determine the character of the rock-beds than to define their extent, the latter may be laid down on the map approximatively, leaving its accurate definition for the second stage of the survey. Every care must, however, be taken to determine rightly the relative age of the beds, for on this the result almost wholly depends. The means by which this determination is effected have been described in the chapter previously referred to.

The nature of the evidence obtained from the geological constitution of a district may be either negative or positive. If the results of the preliminary survey show indubitably that the rock-beds of the Carbon Period are absent, it may be justly inferred that coal does not exist in that locality. And if the same results are obtained throughout the district, further search would be useless; but if, on the other hand, the coal measures are met with, though not absolutely conclusive of the existence of seams of coal, such evidence is positively and strongly in favour of their existence. It is, indeed, only where the measures are found in insignificant fragments that coal is absent. The determination of the carboniferous formations is, however, often a matter of great difficulty, and one that requires long and patient observation. The explorer should be warned against drawing hasty conclusions,

especially concerning the absence of the carboniferous rocks. He will find it necessary in such circumstances to suspend his judgment until he has obtained complete evidence, and, as previously remarked, the obtaining of such evidence will require much time and labour. The configuration and general aspect of the surface, which, in the older formations, never deceive the eye of an experienced geologist, are, in this case, of but little assistance, on account of the readiness with which the carboniferous rocks yield to atmospheric influences. The only indication of this character of any value is that the general aspect of the surface is flat, or varied by low and gently sloping hills. This circumstance renders it difficult to find "sections" of the strata, or bold outcrops from which their character, dip, and thickness can be ascertained. In numerous cases, too, the outcrops are covered by more recent deposits. These circumstances—complicated, perhaps, by the presence of faults—may render it necessary to have recourse to boring, in order to accurately determine the geological constitution of a given tract of country.

When the existence of the coal measures has been placed beyond doubt, or even when a strong probability of their existence has been made out, the second or particular stage of the search will be entered upon. This consists of special observations and investigations, having for their object the discovery of the outcrop of the coal seams, and of exact surveys for the purpose of laying down on the map, in plan and in section, the true extent and positions of the rock-beds among which the seams occur. As the outcrop will in most cases be hidden beneath vegetable soil, a vigilant eye will be needed to detect the traces of it on the surface, and the observer will find it necessary to make use of every possible source of information. He should carefully examine every exposed surface, and especially every "section," such as may be found in roadsides, escarpments, quarries, wells, and the banks of streams. The latter are particularly deserving of attention, for besides showing a section of the strata through which they have cut their way, they afford valuable information of another character. The bed of a stream contains a collection of mineralogical specimens obtained from all the country above the point at which they are found. By ascending the bed of streams, therefore, and examining minutely the pebbles and sands which have been brought down, and noting the height at which fragments whose special character have attracted attention cease, a clue may be obtained to the spot whence they came. Whether this spot be near or remote, may be judged from the more or less worn state of their edges, considered in relation to their hardness. Among the substances indicative of the presence of coal seams, nodules of carbonate of iron merit special mention. Pieces of shale should be examined with particular minuteness for vegetable impressions and organic remains. The latter may often be found in the beds of streams washed clear of earthy matters; these afford evidence of a most important character in determining the existence or otherwise of the object sought. If they be true coal fossils, every care should be taken to trace them to their origin up the country. Small grains of coal may also be found in hollows of the bed, for wherever a seam of coal crops out, it is pretty sure to be crossed in some part by one of the streams in the locality. But even where this is not the case, particles will be carried down to the streams by heavy rains.

When, from all the indications observed, the locality of the outcrop of a coal seam has been determined as nearly as the nature of those indications permit, the surface of the ground must be attentively examined. The observer will bear in mind that the coal measures consist, as described in the chapter on geology, of an alternation of beds of coal, shale, and sandstone, and that each of these resist the disintegrating action of atmospheric agencies in different degrees. Thus, the sandstone is the most enduring, the shale being very destructively acted upon, and the coal still more so

than the shale. Hence the outcrop of the coal seam may be expected to occur in a depression or hollow of the surface, and, therefore, depressions should be looked for, and carefully examined. If a depression is found following everywhere the direction of a ridge formed of protuberant sandstones, it will probably be the outcrop of the seam sought. It must not be expected, however, that the line of depression will be a continuous one; many causes may operate to prevent this. On the contrary, in most cases it will be formed by a succession of hollows, irregular in their intervals and their degree of depression. The action which thus tends to render the position of the outcrop conspicuous, also tends to conceal the seam itself, by bringing down upon it and overlaying it with the detritus of the higher and more durable rocks, especially the contiguous shales. Hence small superficial indications must be looked for. A darker colour of the soil generally throughout a certain breadth of country, such as may frequently be observed in a freshly ploughed field; darker patches of soil here and there; protruding bands of dark shale in certain spots, and minute particles of black carbonaceous matter left as a sediment from water in cattle tracks, or other holes in the surface—any one of these circumstances may be taken as indicative ot the presence of the outcrop. It now only remains to prove the truth of the inferences drawn. This is done by digging small pits, at intervals of a few yards, in a direction, as nearly as can be judged, at right angles to the strike of the beds. These pits must be carried sufficiently deep to pierce the overlying drift. If the outcrop is discovered by these pits, the sinking of others will be proceeded with until the outcrop has been passed in opposite directions, that is, until the line of the trial pits extend beyond the upper and lower boundaries of the seam. The two outer pits on each side of the central one should then be joined by a trench of the same depth as the pits, in order to discover clearly the upper and lower boundaries of the seam, and to ascertain approximatively its dip. It must be remarked here that coal seams often diminish singularly in thickness at their outcrop, so that a seam two or three yards thick may appear at the surface as a mere line of black shale. This fact is probably due to the disintegration and decomposition of the coal by atmospheric agencies, and the consequent spreading of the beds that lie immediately above and below the seam. Hence, if the outcrop is not struck by one of the trial pits, it will be well to join them all by a trench before abandoning the search. When the existence of a seam of coal has been proved in this manner, the bearing of its strike should be determined, and at least two other trials of the outcrop made at about equal distances on each side of the proved point. By means such as these the object of the search is attained, and it only remains to record the information accurately on the map. In prosecuting the search, local traditions should not be neglected; often a hint obtained from such a source will put the observer at once upon the right track, and so save him much time and labour.

Searching in a partially known Locality.—In order to fully understand the character of the search which we have here to consider, it is necessary to possess a clear and definite notion of the nature of the boundaries of a coal-field. A seam of coal may terminate, actually or practically, (1) by cropping out to the surface; (2) by thinning out and being replaced by a bed of another nature; (3) by dipping beneath more recent deposits to a depth too great to allow of its being worked; and (4) by being thrown by a fault of dislocation, either out altogether, or down to an impracticable depth. It will be plain, on reflection, that we shall have to consider only those boundaries which are due to the occurrences described in (3) and (4), since the seam in the former cases (1) and (2) actually and finally terminate. There may be an exception in the case of (1), which will be explained hereafter.

When a seam of coal is lost by plunging beneath a set of beds of more recent formation than

those of the Carbon Period—as, for example, when the coal measures disappear beneath permian or new red sandstone rocks—there is no question of the *existence* of coal in the area covered by the latter beds. The continuance of the seams which have been worked up to the boundary of the district may fairly be assumed. The only question is, Can the seam be reached at any point within a practicable distance of the surface? It is obvious that this question must be answered in the negative if all the conditions remain the same, since the seam, which was abandoned at the boundary of the district in consequence of its great depth, must continue to sink deeper as it passes through the new locality in which it is to be sought. Hence, in this case, the object of the search is not to discover the existence of the seam, as in the preceding case, but to ascertain whether any of the conditions have changed since the seam known to exist disappeared beneath the newer formations. The possible changes are of three kinds, any two or all of which may occur at the same time. The overlying beds may, at no great distance from the point at which they come in over the coal measures, have been subjected to great denudation. This occurrence, provided the seam dipped at a low angle, might so reduce the depth as to render working again practicable. Or the seam may by a synclinal curve be brought up towards the surface. It has been shown, in Chapter I., that the palæozoic rocks were greatly contorted before the deposition of the new red sandstone, which accordingly lies unconformably upon them. Whence it is evident that this second case is by no means remotely probable. Or, again, a fault of dislocation may have occurred to throw the seam nearer the surface. The frequency of such faults renders this case one of peculiar importance.

The first and last of these possible cases may be determined by a careful and detailed geological survey. The principles upon which such a survey is conducted, and the means employed in its execution, having been already fully described, the reader is referred, for information on this subject, to the sections in which the descriptions are given. We here do no more than point out the circumstances and conditions towards which the attention of the observer should be specially directed. The determination of the second case, when the palæozoic rocks do not come up to the surface, necessitates a recourse to boring. Reference has been made to the fact that the outcrop of a coal seam is not necessarily its actual limit in that direction. When the outcrop occurs on an anticlinal, its continuation may be expected on the other side of the curve; and a fault of dislocation may, by a downthrow, bring the seam in again for a distance proportional to the angle of inclination and the amount of the throw. These are questions to be determined by a survey.

The question of the depth at which the extraction of coal ceases to be practicable, is one the conditions of which are constantly changing with the improvements effected in mechanical appliances. The determination ot the question is almost entirely dependent upon the means possessed of raising the coal to surface, and of providing sufficient ventilation; and as these means are improved, pits are sunk deeper and deeper, so that depths formerly considered altogether impracticable are now of common occurrence, and in some instances are greatly exceeded. The deepest coal workings in England are those of the Rosebridge Colliery, near Wigan, which are situate at 2400 feet from surface. But in Belgium there is a colliery now being worked, the depth of which exceeds 3400 feet. As, however, it seems hardly possible to raise coal through a greater height than 2500 feet in one lift, we must consider this the present limit, though, with better appliances and other arrangements, it is probable that coal seams may be successfully worked at much greater depths. This limit is that which is imposed by the conditions of winding and ventilating, and may be termed the *mechanical* limit, inasmuch as it is dependent on mechanical appliances. But the thickness and

quality of the seams may be such as to render this depth far too great to allow of profitable working. Thus we have another limit which, being dependent on commercial circumstances, may be called the *commercial* limit. The latter must be determined for each individual case from the data possessed.

Determination of the Character of a Seam of Coal.—With the determination of the existence of a seam of coal, the labour of the mere geologist ends, and that of the mining engineer proper begins. It would be an exceedingly hazardous venture to undertake the opening out of a colliery, and the erection of costly plant for its development, in reliance upon the evidence obtained from the survey alone. Before commencing the extraction of the discovered mineral, and, indeed, before making any preparation for its extraction, prudence will dictate further researches, involving a large expenditure both of time and money certainly, but indispensable to safety from ultimate failure. Every seam of coal is not profitably workable. The necessary, though not sufficient, conditions which a seam must fulfil to be considered of a workable character are, that it shall be sufficiently thick, of considerable extent, and of suitable quality. Besides these essential conditions, there are others of grave importance, such as the character of the roof, the inclination and regularity of the seam, and the nature of the strata which will have to be sunk through, claiming careful and early attention. To determine accurately and clearly these conditions is the object of the researches which it is incumbent upon the engineer to make in continuation of the labours of the geologist. The methods of prosecuting these researches are (1) by headings, (2) by trial pits, and (3) by borings.

When the outcrop of a seam of coal has been discovered and tested in the manner previously described, its character may be partially determined by driving headings or drifts into it to a sufficient depth. Such headings may be driven in the seam following the direction and inclination of the strata, or horizontally to cut the seam in a given point. Generally the former plan will be preferred when the angle of the dip is low, and the latter when the beds are highly inclined. In choosing the spot for a trial heading, care should be taken to avoid such as are liable to be flooded by surface water during heavy rains. If the excavation is to be an inclined one, this precaution is especially necessary. Supposing the heading to be of this character, and a suitable spot determined upon, the excavation will be commenced in the outcrop of the seam. The dimensions will be the least possible consistent with convenience of working. The minimum imposed by this condition is 3 feet wide by 4½ feet high; but in general it is better to allow more space than this, 4 feet by 5 feet 6 inches being more suitable dimensions. In any case, however, excepting, perhaps, seams of extraordinary thickness, a sufficient height must be given to the heading to remove the whole of the seam, so as to discover the character of the roof and the floor. It has already been remarked that coal seams often diminish greatly in thickness at the outcrop. Whatever the character of the roof may be, some timbering will be required, for the strongest rocks become tender and broken up by fissures near the surface of the ground. The methods of timbering and the means employed in making the excavation being precisely the same as those applied in driving the levels for the deep workings, the description of them will be reserved for a subsequent chapter.

The explorer will not be discouraged by the inferior quality of the coal met with at the commencement. The action of atmospheric agencies will necessarily have greatly deteriorated the quality near the outcrop; and its physical condition will have suffered no less than its composition. At first it will be extremely friable, and will exhibit hardly a trace of stratification or cleat, being in a completely disintegrated state. It will also be largely mixed with earthy matters introduced by infiltering water holding them in suspension. But these qualities gradually disappear as the heading

progresses, and the latter should be continued until it has got beyond the reach of atmospheric influences, when the true character of the coal will appear. It must not, however, be supposed that the actual quality of the coal will ever be seen in a heading. This is found only at a considerable distance from the surface; but sufficient indications will be obtained of what will be met with at greater depths. When the heading has been carried far enough to attain the object sought, branches or side drifts should be thrown out at right angles to the heading, so as to expose a larger face of coal, for the purpose of forming a more accurate estimate of its character. During the progress of these excavations every care should be taken to determine exactly the dip of the seam and the character of the adjacent rocks.

When the strata are inclined at a considerable angle, or when the infiltration of water into the excavation is feared, a horizontal heading will be preferred. Such a heading, however, like the so-called "levels" of the deep workings, is not strictly horizontal, but is slightly inclined outwards from the face, for the purpose of discharging any water that may enter, and to facilitate the extraction of the broken rock. When, from the preliminary observations, the dip of the beds has been approximatively determined, a suitable spot beneath the outcrop of the seam is selected for the opening of the excavation. The distance of this spot below the line of the outcrop is made such that the heading will strike the seam at a point sufficiently remote from the outcrop to afford the required information. The heading is driven through the seam, and side drifts put out in it at right angles to the heading, as in the preceding case, and for the same purpose. The horizontal heading, besides the advantages afforded for extracting the rubbish and keeping the workings free from water, furnishes a better neans of discovering the character of the adjacent rocks.

Instead of headings, vertical pits are sometimes resorted to for the purpose of ascertaining the character of a seam. The pit is located above the outcrop, and at such a distance from it that the evidence obtained when the seam is struck shall be sufficiently indicative of its character. This method is usually more expensive than the preceding; but a better knowledge of the superjacent rocks is obtained by it. The same knowledge would, however, be afforded by the horizontal heading if the latter were continued sufficiently far beyond the seam. Generally, headings should be preferred to trial pits, except when the strata are nearly vertical, in which case pits can alone be employed.

Boring affords the only means of determining whether the seam be continuous or not over a given area. The operation consists in excavating a hole of only a few inches in diameter, by means of suitable tools fixed to the end of a line of rods worked from the surface, which line is lengthened as the hole progresses in depth. The rubbish formed at the bottom of the hole by the cutting action of the tools is extracted from time to time by means of other tools specially designed for the purpose. By making alternate use of these two sets of tools, the hole is gradually deepened, and the nature of the bed which is being passed through is ascertained from the rubbish brought up from the bottom of the hole. By means such as these, a hole may be bored to a depth of 2500 feet, the limit of workable depth previously described. A number of such bore-holes judiciously distributed over the area under examination will determine in the most decisive manner the character and thickness of a seam of coal; its dip and continuity; the number, direction, and amount of throw of the faults of dislocation, if any exist; and many other questions of the gravest importance to future mining operations, such as the nature of the superjacent rocks, and the existence of water-bearing strata.

In determining the position of the bore-holes, it will be borne in mind that no bed cropping out on the dip side of the boring will be passed through, and that the depth at which the seam will be

struck by a second boring farther to the dip, may be accurately calculated from the horizontal distance between the two borings, as explained in Chapter I. If the seam is not met with at that depth, it may be inferred that some interruption exists, the character and extent of which must be made the objects of further search.

We have already alluded to the use of boring in searching for seams of coal under conditions in which no other means are available. Besides this use, it may be applied to the discovery of parallel seams existing above or below the one upon which attention has been directed.

Boring constitutes, indeed, the most valuable means which the mining engineer has at his disposal, not only for revealing the existence of seams of coal, but also for ascertaining their actual character at any given point, and the conditions that will be encountered in sinking the shafts to it. To these circumstances it is due that the use of this means has of late been rapidly extending, and it is destined no doubt, with improved appliances, to take a more important position than it now occupies among engineering resources.

BORING OPERATIONS, AND APPLIANCES THEREFOR.—The tools used in boring penetrate rocks by percussive action, that is, by having their cutting edges forcibly and repeatedly applied to them in a manner to constitute a rapid succession of more or less heavy blows. Each blow chips off small fragments of the rock, and in this way, by the continued action of the tool, the rock is gradually worn away. But if the blows were continually delivered upon the same point, this chipping action could not take place, and the tool would merely pound the rock to a powder at that point without making much onward progress. Moreover, in such a hole as would be produced by that means, the tool would soon become fixed, and farther advance would be rendered impossible thereby. Hence, in addition to the reciprocating motion required to produce the percussive effect, it is necessary to impart a rotary motion to the tool, the two motions being so proportioned to each other that the edge of the tool may not fall twice in the same place. As the motions have to be transmitted from the surface to the tools at the bottom of the bore-hole, the apparatus required for the purpose will evidently consist essentially of three distinct portions: the tools by means of which the excavation is effected; the medium through which the motion is transmitted; and the appliances by which the motion is produced. The first consists of cutting, clearing, verifying, and regulating tools; the second, of iron or wooden rods; and the third, of shear-legs, pulleys, windlasses, levers, and other implements forming the surface apparatus or head-gear. It will conduce to a clear understanding of the subject to describe these portions separately.

Cutting Tools.—The term "cutting" tool applied to an instrument for penetrating rock is not a strictly correct one. The student who has examined the mineral composition of rocks will have recognized the impossibility of *cutting* them, in the ordinary acceptation of that term, inasmuch as the rock constituents are frequently harder than the tools which are used to penetrate them. This fact has, as we shall see later, very important practical bearings. When a rock cannot be cut, the only way of removing portions of it is by fracturing it by a blow delivered through the medium of a suitable instrument. Hence it is that the percussive action is adopted in all rock-boring operations, as already explained, the end to be attained being the removal of the rock by a constant process of *chipping*. To effect this chipping, the instrument used must present only a small surface to the rock so as to concentrate the force, and that surface must be bounded by inclined planes or wedge-shaped surfaces so as to produce a lateral pressure upon the particles of rock in contact with them. In other words, the instrument must be provided with an edge similar to that possessed by an ordinary *cutting*

tool. The conditions under which the instrument is worked are obviously such that this edge will be rapidly worn down by the friction against the harder rock materials, and by fractures. To withstand this destructive action, two qualities are requisite in the material of which the instrument is composed, namely, hardness and toughness. Thus there are three important conditions determining the suitability of a cutting tool to be used for rock boring: the necessity for a cutting edge; the necessity for a frequent renewal of the edge; and the necessity for the qualities of hardness and toughness in the material of the tool. The difficulty of satisfying these conditions has led to extreme simplicity in the form of the tools. The question of the most suitable form for penetrating hard rock has received much attention, and numerous modifications have been proposed; but nearly all have failed in practice, and consequently have been abandoned because of their unsuitable character in relation to the second condition. When it is borne in mind that a boring tool cannot be used in hard rock for longer than a few hours at the best without resharpening, the importance of this condition will be recognized. The form of the tool may be admirably adapted for penetrating the rock, but if it be a difficult one to work upon in the smithy, where the tool must necessarily be perhaps several times in a day, it is obvious that more time may be lost upon the forge than is gained in the bore-hole. Hence, as the result of experience in this direction, all complicated forms, except for certain special purposes, have been generally abandoned, those at present in use being the simplest forms first employed, or those forms very slightly modified. It will be apparent from the circumstances referred to in the foregoing statements, that the smithy holds a very important relation to the boring apparatus. As a matter of fact the success of the undertaking depends in a notable degree upon the care and skill with which the smith's work is performed. But as we shall have occasion in the next following chapter to treat of the hand-boring tools that are of daily use in every mine from the time when the shaft is begun to the time when the last load of mineral is drawn, we shall defer our remarks on this subject, as well as on that of the quality of the metal, till that opportunity. It should, however, be remarked here, as appropriate to the subject in question, that the smith must be recommended to exercise especial care not to alter the dimensions of a tool he is required to work upon; and as a precautionary measure, it will be prudent, whenever a tool has been returned from the smithy, to pass it through a ring of the requisite diameter before lowering it into the bore-hole. If this precaution be neglected, grave injury may result to the sides of the hole, or irregularities may be produced that may occasion insuperable difficulty should it subsequently become necessary to tube the hole.

The simplest form of tool is shown in Figs. 161 and 162, Plate XIII., and is known as the "flat chisel," or "straight bit." It is formed of the toughest wrought iron, and steeled at its cutting edge with the best material. The length is usually 18 inches; at the upper end it is provided with a thread by means of which it is screwed to the rods. The breadth of the cutting edge is, in this example, 3 inches; and it may be remarked here that the whole of the tools and appliances illustrated in this chapter are for a bore-hole of 3 inches diameter. This form of tool is of very common use, being applicable to all but the softest and hardest strata. The ease with which it may be resharpened is a quality that commends it to the choice of the practical man.

The form shown in Fig. 163 is designed for penetrating hard rock, and is variously known as the diamond-point drill or V-chisel. This tool differs from the preceding only in the form of its cutting edge, which is very suitable for rock of a highly resisting character, and which offers but little more difficulty in the smithy than the straight edge of the flat chisel.

Figs. 164 and 165 represent another form of chisel, intended for piercing very hard rock. This form is commonly employed on the continent of Europe; but though it effects very satisfactorily the object for which it was designed, the difficulty of resharpening and repairing it has prevented its general adoption in this country. Like the preceding, it differs from the first only in the form of its cutting edge.

For boring through gravel, the form of cutting tool shown in Fig. 166 is used. It consists of two cutting edges at right angles to each other, one of them being curved towards the extremities. This form, which in other respects is identical with the foregoing, is known as the T-chisel.

For boring through soft clay or loose sand, the auger, Fig. 167, is employed. This tool is very similar to that used for boring in wood. The bottom is partially closed by the lips, which are turned down to a greater angle than in the case of wood augers. The clay auger is made of greater length than the chisel bits, but it terminates upwards in the same form as the latter. Usually it is half cylindrical, as in the figure; but sometimes it is made wholly cylindrical, with the exception of about six inches at the bottom, where it is left open to allow of the admission of the material being bored through. When used in clay, this tool, on being raised to surface, carries the core with it.

The angle of the edges of cutting tools is determined by the character of the rocks to be penetrated, the obtuseness increasing with the hardness of the rock. Too small a degree of obtuseness is to be especially avoided, since the fracture of the edge not only diminishes the efficiency of the tool and necessitates repairs on being drawn to surface, but, by leaving fragments of hardened steel at the bottom of the bore-hole, is liable to cause the same injury to the tools subsequently lowered. It is a good plan to test every fresh tool before fixing it to the rods, by dropping it from a considerable height, edge downwards, upon a hard stone.

Clearing Tools.—When the action of the cutting tools has been continued sufficiently long to produce a mass of débris at the bottom of the hole, it is necessary to remove that mass; for it is evident that the presence of those materials will tend to diminish the action of the tools upon the rock by forming a protective covering. Hence an accompanying set of tools is needed for the extraction of the rubbish. As in the case of the cutting tools, many forms have been designed for this purpose; but though the same conditions do not hold, only the simplest remain in common use. These tools may be divided into two classes: those which act by rotary motion, and those which act by percussion. The former are attached to the rods in the same way as the cutting tools, and are worked by simply turning the rods; the latter are not used with the rods, but are jerked up and down in the bore-hole on the end of a rope. The following are the clearing tools in common use:

The most generally employed tool of the revolving class is that represented in Fig. 169, and known as the "auger-nose shell," or "wimble." It is of the same form and dimensions as the cylindrical clay auger, with the exception of the diameter of the cylindrical portion, which, as in all clearing tools, is slightly less than that of the cutting tools. To prevent the escape of the loose material, it is furnished on the inside with a valve. It has already been remarked that the clay auger removes the material from the hole, and therefore does not necessitate the use of a clearing tool. Another form of tool, known as the "flat-nose shell," is shown in Fig. 170. This tool differs from the preceding only in the form of its lower extremity, which is flat, and not open at the side: it is provided with a valve for the retention of the material, as shown in the figure.

For use in harder ground, a modification of the preceding form has been adopted, known as the

"shoe-nose shell." The point of this tool, shown in Fig. 171, enables it to sink into the debris more readily, and also to gather it into the part above the valve.

Occasionally a pebble, a flint, or a hard piece of rock will get into the bottom of the bore-hole, from which it cannot be readily extracted by the ordinary valved clearing tools. In such cases recourse must be had to the special tool, represented in Fig. 168. This tool, which is called a "wad-hook," consists of two steel spiral blades, arranged as shown in the figure. A few turns of the rods are generally sufficient to make the blades clasp the obstruction, which may then be withdrawn without difficulty. The wad-hook may also be used for extracting a broken tool, as will be explained later.

The foregoing revolving tools clear the bore-hole very effectively, and this is a merit which can hardly be exaggerated, since the presence of debris, as before remarked, tends greatly to retard the progress of the operation. But they have one serious defect, namely, that of requiring much time and labour in lowering and raising, connecting and disconnecting the rods. The tools of the second class are not open to this objection, inasmuch as they are lowered rapidly by a rope. This class of clearing tools are called sludgers, from their being employed to remove the debris, as *sludge* or mud, from the bore-hole. Numerous forms have been given to sludgers also, but the only one that has continued in general use is the simple ball-valve sludger, represented in Fig. 172.

This instrument consists of a wrought-iron cylinder of the same dimensions as the shells already described, and similar to the latter in external appearance, with the straight portion of the shank removed. The lower extremity is furnished internally with a ball-valve; this valve is either of wood or of metal, preferably the latter, and its weight is proportioned to the degree of fluidity of the matters to be extracted. It rests, as shown in the figure, upon a conical seating formed by an annular piece riveted to the cylinder. As previously stated, the sludger is worked by jerking it up and down in the bore-hole. During the descent of the tool, the valve is raised by the water in the hole; for it must be borne in mind that the presence of water is essential to all boring operations, and that, therefore, when water does not enter through the strata, it must be supplied from above. The weight of the sludger causes it to sink into the debris which is thus forced above the valve. As the sludger ascends, the material which has entered acts with the water to close the valve. By this means, the escape of the sludge is prevented, though a large portion of the water passes out through the accidental interstices occasioned by small pieces of stone upon the valve seating. The action of the sludger is very effective, as much as a cubic yard having been removed at one time by a large tool. When the operation of "pumping" the sludger has been continued sufficiently long to clear the hole, it is raised, and its contents removed by turning it upside down. On account of the facility with which this clearing tool may be used, it is very generally adopted. It may be said, indeed, to occupy among clearing tools the position occupied among cutting tools by the flat chisel.

It has been proposed, for the purpose chiefly of saving time, to remove the debris from the bore-hole during the operation of cutting by means of a jet of water. This proposal has in many instances been adopted with success, by the employment of hollow rods, through which the water is forced by means of a pump connected with the rods by flexible tubing. The advantages of the system when used with the ordinary boring tools have, however, been overestimated. The work of cutting has to be frequently suspended to raise the rods for the purpose of renewing the tool, so that the only time that can be saved is that during which the sludger is being used. But as this tool can be very rapidly lowered and raised by means of the rope, it is not long in the bore-hole. Thus the advantage

gained in time, is compensated by the necessity of employing hollow rods, which, for small borings, must be of larger diameter than the solid bars, and more expensive.

Verifying Tools.—The materials brought up by the clearing tools show the nature of the stratum that is being passed through. But as these materials are in a divided state, being reduced to small fragments by the action of the chisels, they indicate but little of the physical condition of the rock-bed, and nothing whatever of its dip. Moreover, their indications concerning the nature of the bed are hardly trustworthy, inasmuch as particles of the higher beds are continually falling from the sides of the bore-hole. As it is highly desirable that full information on all points should be obtained when boring in search of coal, and especially on the dip of the beds, their physical character, and their geological age as evinced by contained fossils, it becomes necessary to have recourse to special tools for that purpose. The use of such tools is to bring up a solid core of the rock, and to bring it up in such a condition that the lines of stratification will show the dip of the bed. To obtain this result, the core must be marked relatively to the north point before it is broken from the rock. This is effected by means of a chisel with an eccentric cutting edge. Having previously cleared out the hole, this chisel is lowered, care being taken, by suitable marks on the rods and a fixed plumb-line, that it be not turned in the least degree during the operation. When it has reached the bottom of the hole, two or three light blows are struck without turning the rods, and it is again raised. A special tool, Fig. 173, Plate XIII., composed of a number of chisels set in a ring, is then lowered, and worked with light blows in the same manner as the common chisel. By this means an annular space is cut round the marked core. When this space has been cut nearly to the depth of the chisels, the tool is raised, and another special extracting instrument, Fig. 174, let down. This instrument drops over the core, and by means of a wedge thrust in by the weight of the rods, exerts a sufficient lateral pressure to break it off. The core is held between the wedge and a spring fixed on the inside of the instrument for that purpose, and in this way it is raised to the surface. The inclination of the lines of stratification may then be observed relatively to the mark upon the upper end, and the direction and amount of the dip determined. By repeating this series of operations, a complete section of the strata may be obtained.

Regulating Tools.—Besides the foregoing cutting, clearing, and verifying tools, others are occasionally required for the purpose of regulating the diameter of the bore-hole, or of restoring it to its original dimensions when the hole has partially closed in by the swelling of the clay beds. One of these is shown in Fig. 175; it is worked by combining the vertical and rotary motions, and may be used at any height in the bore-hole. The tool shown in Figs. 176 and 177, and formed of a helical blade steeled at the edges, may be used in the same manner and for the same purpose, or for boring through feebly coherent sand-rock.

Rods.—The rods by means of which the excavating tools are worked from the surface constitute a very important part of the boring apparatus. They consist usually of bars of iron one inch square, for borings of ordinary dimensions. Other sections have been employed, notably the circular and the octagonal; but the greater simplicity of the square section, and the advantage which it possesses of allowing the application of keys and spanners to any portion of its length, have caused it to be preferred to the more complex forms. As fracture of the rods is likely to be attended with disastrous consequences, and as moreover they are subjected to constant shocks, it is very important that only the best material should be employed in their construction. Swedish iron of the toughest quality should be chosen for this purpose. In judging of the quality by the appearance, only such

samples are to be relied upon which are of a soft and fibrous character, and possess a clear, smooth skin free from cracks, and full sharp edges. To test the sample by fracture, one side of the bar is slightly nicked with the chisel, and the bar bent slowly to and fro until it breaks. If the iron is of good quality, the fractured surface will exhibit fine, bright, silky-looking fibres of some shade of dark-grey colour. A bar of such iron of one-inch section will break with a tensional strain of about 28 tons, while a bar of the same dimensions, but of average quality, will yield with a strain of 20 to 23 tons.

The rods are generally made up of 10 or 15 feet lengths. It is evident that the fewer the number of joints in a rod, the better it is in many respects, and hence attempts have been made to reduce the number by employing lengths as great as 25 feet. But, for reasons which will hereafter appear, such lengths are inconvenient in use, and they have consequently been abandoned in favour of those mentioned above, the greater length being the one which satisfies most fully the conditions imposed. A few shorter lengths, forming a convenient fraction of the main lengths, are required for the purpose of keeping the "head," or upper extremity of the rods, within a certain distance of the surface of the ground as the sinking progresses.

The several lengths of rod are connected by a screw-joint. Other modes of connection have been employed, but all have failed in practice, some for one reason and some for another, leaving the screw-joint in universal use. One end of each length of rod is provided with a male, and the other end with a female screw, as shown in Fig. 178, Plate XIV. The thread is of the simple triangular form, and makes not fewer than six revolutions. The section of the cylindrical portion upon which the thread winds should be equal to that of the rod, namely, one inch; hence the section of the rod must be increased at each end to allow for the thread of the male and the sides of the female screw. This will make the diameter of the rods at the joints about twice that of the solid section. The female socket should be bored a little deeper than the length of the male plug, in order to bring the sides of the former in close contact with the shoulder of the latter. This joint may yield either by the force of the shock slipping the thread, a liability that is greatly lessened by bringing the sides and shoulder firmly together; or, which is a far more common case, splitting the sides of the socket. The only means of obviating the latter contingency is to give the sides a sufficient section, and to reduce as much as possible the shock of the falling rods. All the joints should be identical in every respect, so that any two lengths may be connected together; and in making up the rod, care should be taken always to have the socket on the lower end of each length, to prevent rubbish from being jammed into it. The enlarged portion at the joint serves as a point of support to suspend the rods from during the operations of raising and lowering.

A grave objection to the employment of iron rods for deep borings is their great weight. A rod of one-inch section, such as we have been describing, weighs, exclusive of the increased quantity of metal at the joints, 10 lb. a yard, and as the specific gravity of iron of that quality is about 7·78, a yard immersed in water will weigh 8·7 lb. Hence the rods in a bore-hole 300 yards deep will weigh $8 \cdot 7 \times 300 = 2610$ lb., or upwards of 1 ton 2 cwt., and a depth of 600 yards will give a weight of $2\frac{1}{4}$ tons. It is obvious that in practice serious difficulties must result from this circumstance. So great a weight distributed throughout a long length of rods cannot be suddenly arrested by a shock applied to its lower extremity without throwing a dangerous strain upon the rods near the bottom, and causing them to vibrate violently against the sides of the bore-hole—consequences that would be extremely perilous to the success of the undertaking. Two methods have been pro-

posed of overcoming this difficulty: the first is the substitution of wooden rods for the iron ones when the depth is great. Such rods, with their iron connections, lose the greater part of their weight in water, and thus are not exposed to the danger mentioned. They have been successfully employed in many instances. These rods are made of sound, straight-grained pine, in lengths of 25 and 35 feet, have a square section of not less than $2\frac{1}{2}$ inches side, with the angles slightly planed off. They are connected by iron screw-joints in the same manner as the iron rods, each end being provided with an iron joint-piece forming a socket into which the rod is bolted, as shown in Fig. 179. A fatal objection to wooden rods for small borings is the necessity for a large section. Less than 2 inches side could not be used, and for great depths 3 inches and 4 inches would be required. But when the bore-hole is of sufficient diameter, they may be employed with advantage in some cases, and as a matter of fact, they are frequently adopted for deep borings on the continent of Europe.

The second method proposed possesses greater advantages, inasmuch as it removes the difficulty without abolishing the iron rods. It consists in forming the rods of two distinct portions: a short and massive part at the bottom, to which the cutting tool is attached, and on which alone the force of the shock is expended; and the rod proper, which is used solely to raise the former part, and which, not being attached to it in an invariable manner, is not exposed to the shocks occasioned by the percussive action of the former. As this method allows all the advantages attending the use of iron rods to be retained, it is by much the more important of the two, and has, consequently, been very generally adopted.

The forms of construction by which the latter method has been carried out have undergone numerous modifications since its first introduction. But, as in the case of the tools, the lessons of experience have led to the abandonment of all or most of the recent devices in favour of the extremely simple form which was first proposed, and which is due to the inventive genius of Œynhausen. This joint is known as the "sliding joint," and is the only one that can be relied upon for borings of an ordinary character; for it must be evident that complicated devices are totally unsuitable for use at the bottom of a deep bore-hole where they are far removed from reach and sight. The construction of the sliding joint will be clearly seen in the three views given in Figs. 180, 181, and 182. The lower part to which the cutting tool is affixed terminates upwards in a head moving in a slot in the lower extremity of the upper portion constituting the rods proper. When the rods are raised, the tool is lifted by this head, which then rests upon the bottom of the slot. On dropping the rods to produce the percussive action of the tool, the latter falls with the former till it comes in contact with the rock at the bottom of the hole, when it is abruptly arrested and thereby subjected to a violent shock. But the rods continue the descent by allowing the head of the arrested portion to slide up in the slot, and by that means the shock is confined to the part carrying the tool. As soon as the head of this part begins to move up the slot, the end of the lever at surface to which the rods are attached comes in contact with an elastic stop which is capable of bringing the rods to rest within the space allowed by the play of the slot. In this way the descent of the rods is gradually arrested, and injurious shocks avoided, without diminishing in any degree the action of the cutting tool. Another advantage of no small importance that has been gained by the use of the sliding joint is the possibility of considerably reducing the section of the rods, which are required only to raise the part to which the tool is affixed.

Guides.—Sometimes in borings of moderate depth, when the sliding joint is not used, guides are employed to prevent dangerous vibration of the rods. These may consist of a kind of cage

constructed of small iron rods of circular section, as shown in Fig. 185, and offering but little resistance to the passage of water; or of a wooden or an iron cylinder encircling the rods and provided with water passages. But a more efficient means of avoiding resistance from the water is to allow the cylinder to play between two stops on the rods, placed at a distance apart somewhat greater than that passed through by the rods at each stroke.

Stirrups.—For the purpose of suspending the rods from the oscillating lever or the pulley, the top length of the rods terminates above the surface of the ground in a stirrup, the construction of which allows the rods to be turned round during the operation of boring and to be lowered as the boring progresses. Several forms of stirrup are in use, but the most convenient is that represented in Figs. 183 and 184. This stirrup keeps the upper end of the rod always at the same height above the ground, a necessary condition for the perfect working of the lever, and it enables the borer to see exactly the progress that is being made at the bottom of the hole. The construction of the stirrup will be clearly seen in the figure. Sometimes the rods are suspended from the lever by means of a chain fixed at one end by a ring to a hook on the upper side of the lever, and having at the other end a hook which is passed through the eye of a swivel head on the upper length of the rods, and inserted in one of the links. The swivel head allows the rods to be turned without twisting the chain, and the lowering of the rods may be effected during the progress of the boring by removing the hook to the next lower link. The use of the stirrup is, however, in all cases to be recommended.

Head-Gear.—The head-gear consists of shear-legs or a boring frame, with the accessory parts and appliances for raising, lowering, and turning the rods. The use of the shear-legs is to furnish an elevated point of support from which the rods may be conveniently suspended. In construction, they may vary, according to the importance of the boring, from a simple tripod formed of scaffold-poles lashed together at the top with rope, to a complete framed structure similar to the permanent head-gear erected over a drawing shaft. But as the erection is in every case only a temporary one, and as it may be required in another locality when the bore-hole over which it is erected is finished, whatever the importance of the work may be, it must be very simple in construction, and so designed that it may be readily erected and taken to pieces without the assistance of skilled workmen.

The height of the boring frame is mainly determined by the depth of the boring. It has already been remarked that the rods have to be very frequently raised for the purpose of changing the cutting tool; it will be evident that the time required for this operation will depend in a great measure upon the height of the boring frame. If the height of this structure were equal to the depth of the bore-hole, the rods might be withdrawn at one lift. If it were equal to half the depth, one half the length of the rods might be withdrawn at one lift; but this half would then have to be disconnected from that remaining in the bore-hole by unscrewing the joints, and the latter half subsequently raised by a second lift. So if the height of the frame were one-fourth the depth of the hole, the rods would have to be raised in four lifts, and three joints would have to be unscrewed. Thus it will be seen that a high boring frame saves much labour and time, by increasing the length of the "offtake," as it is called; and that for deep borings a high frame is practically indispensable. The height found most convenient in practice is between 30 and 45 feet; in some instances, 60 and even 80 feet structures have been employed, but such structures must necessarily be of a complicated character. Whatever the height may be that is adopted, it is essential that it be a multiple of the lengths of which the rods are made up, so as to bring the joint to be unscrewed a convenient distance

above the top of the bore-hole. Thus, if 15-feet lengths are employed, the boring frame must be 30 or 45 feet high; whilst if the lengths are only 10 feet, the height must be either 30 or 40 feet.

Besides a considerable height, great strength is essential to a boring frame. Perfect rigidity in the support is necessary to the efficient working of the apparatus, and this rigidity can be obtained only by means of ample dimensions. It must be borne in mind when designing a boring frame, that the strain thrown upon it while raising the rods by means of a pulley and windlass is equal to the tension of the rope increased by the weight of the rods and their accessory parts, or, more generally, equal to the tension of the rope increased by the resistance of the rods, which will be greater than their weight in cases when they have by some accident become jammed in the hole.

The support furnished by the top of the boring frame is provided with a pulley, usually of cast iron, and grooved to receive a rope. This rope is attached at one end to the rods, and at the other to a windlass, by means of which the rope is drawn in and the rods raised. This windlass forms an essential part of every boring frame. It is in most cases fixed upon the frame at a convenient height above the ground, and is worked either with an intermittent motion by levers and ratchet-wheel and paul, or with a continuous motion by crank handles, as in the case of a common drawing well. The former method is unsuitable for any but small depths, and even in such cases is inferior to the latter. Sometimes the windlass is arranged with a vertical axis, and worked with horizontal bars, like a capstan. When the depth and, consequently, the weight of the rods, become great, the windlass is worked by intermediate gearing, which may be so contrived as to increase the speed when a large portion of the weight has been taken off. In very deep borings, a steam-engine may be used to work the windlass. In all cases a brake is attached to regulate the descent of the rods.

The sludger is the clearing tool generally employed, and being used independently of the rods, it is usually provided with a special pulley and windlass of smaller dimensions. This windlass is, like the larger one, fixed to the boring frame, but, for convenience, upon the opposite side, and furnished with a sufficient quantity of rope. The pulley is so contrived that it may be run out exactly over the bore-hole when about to be used, and back again out of the way of the rods when done with. The sludger being swung over the hole, is lowered rapidly by its own weight, its descent being checked by a brake upon the windlass. To raise it, the windlass is turned by crank-handles, and these are also made use of to produce the reciprocating or "pumping" motion required to fill the sludger. But sometimes this motion is derived from the oscillating lever by winding the rope two or three turns round the head.

The simplest form of shear-legs, which may be employed for shallow borings, consists of three fir spars set in a triangular frame at the bottom, and connected at the top in the manner shown in Figs. 186 and 187, Plate XIV. The spars should be of perfectly sound and straight Norway fir, and not less than 8 inches in diameter at the bottom. They should be loosely mortised, and firmly wedged into the bottom framing, or fixed to it by iron straps and bolts. This bottom framing can never be dispensed with. The spars are fixed at the top by placing the head of the middle one between the heads of the two others, and passing a bolt 1 inch in diameter through them. This bolt also passes through the eyes of a wrought-iron sling, which carries the pulley, as shown in the figure. The windlass may be fixed upon the two outside legs at a vertical height of about 3 feet 9 inches from the ground. One of the legs should be provided with staves fixed to its outer side, to enable a workman to ascend to the pulley.

A modification of this construction of shear-legs, more suitable for deeper borings, where the strain due to the weight of the rods becomes greater, is shown in Figs. 192 and 193, Plate XV. In this example, the two legs upon which the windlass is fixed are stayed by cross-bars or ties mortised into the legs and keyed on the outside. The lower ends of the shear-legs are fixed into a triangular wooden frame, and connected at the top in the same manner as in the preceding example. The pulley may also be slung in the same way, or fixed as shown in the figures. Figs. 188, 189, 190, and 191 show several modes of connecting shear-legs and fixing the pulleys.

The simplest form of boring frame is shown in Figs. 194 and 195. It consists of two pairs of shear-legs inclined towards each other, and held in their positions and stayed by ties or cross-bars mortised into the legs and keyed with wooden keys. The lower ends of the legs may either be set in the projecting extremities of the side pieces of a rectangular frame, or, if the bottom tie be placed within a foot from the ground, the ends may be supported upon brick foundations about 18 inches square, and capped with wood or flagstone to distribute the pressure, the top of the foundation being level with the surface of the ground. When the latter plan is adopted, ties will be required between each pair of shear-legs; but with the bottom frame, these, as well as the bottom tie of each pair, may be omitted. The pairs are connected at the top by two cross-pieces notched and bolted to the inside of the legs. As these pieces form the support for the pulley, they require to be firmly fixed and to possess ample dimensions. In the example referred to, the section is 8 inches × 3 inches, and the diameter of the bolts $\frac{1}{2}$ inch. The shear-legs are 6 inches × 4 inches at the bottom, tapering to 5 inches × 3 inches at the top. The ties are $3\frac{1}{2}$ inches × 2 inches, 3 inches × $1\frac{3}{4}$ inch, and $2\frac{1}{2}$ inches × $1\frac{1}{2}$ inch, reckoning from the lowest upwards. The pulley is of cast iron, 16 inches in diameter. The windlass is fixed upon one pair of the shear-legs, and consists of a wooden barrel 10 inches in diameter, turned by an iron crank-handle. This frame is suitable for borings of an inconsiderable depth only.

For deeper borings a frame similar in construction to that shown in Figs. 196 and 197 will be required. This frame is composed, as in the preceding case, of two pairs of shear-legs, the timbers of each pair being inclined towards each other, and stayed at intervals by ties. But in the present example, on account of the increased height and the greater strains contemplated, the staying is repeated between the two pairs of legs. The bottom tie on each side is, however, omitted for the convenience of the men at work. The legs are 6 inches × 6 inches, and of the same scantling throughout the whole length; they are set in the projecting ends of the side pieces of a rectangular wooden frame, 12 inches × 8 inches, and connected at the top, the timbers of each pair by being mortised into a cross-piece of the same dimensions, and the two pairs by cross-pieces also of the same dimensions, notched into the former pieces, and nailed down to them. Upon these latter pieces, at right angles to them and parallel with each other, two other pieces are fixed over the centre of the frame to support the pulley, as shown in the drawing. The tie-bars are mortised into the shear-legs and keyed as in the preceding example; they are all equal in section, 4 inches × $2\frac{1}{2}$ inches. The pulley is of cast iron, and 16 inches in diameter. The windlass—the barrel of which is of wood 15 inches in diameter, and provided with horns—is fixed upon one pair of the shear-legs. Sometimes a roof is thrown over the pulley, as a protection from the weather.

For deep borings by hand power, the frame shown in Figs. 198, 199, and 200 is, perhaps, the most suitable that could be devised. This boring frame consists of two pairs of shear-legs, of 12 inches × 9 inches scantling, set into the projecting ends of the side pieces of a strong rectangular wooden

framing, constructed of balks, 12 inches × 9 inches for the side pieces, and 9 inches × 9 inches for the end pieces. The timbers of each pair of legs have a slight inclination towards each other, being 3 feet 8 inches apart at the bottom, and 14 inches at the top in a vertical height of 30 feet. These timbers are stayed at intervals of 3 feet by horizontal wooden ties, each 9 inches × 6 inches, mortised into them, and keyed on the outside with wooden keys. The two pairs of legs are connected at the top by two cross-pieces into which they are mortised: these pieces carry the pulleys. One pair of the shear-legs is provided with stout diagonal timbers fixed between them and the bottom framing, for the purpose of carrying the windlass, which is moved by spur gearing, and furnished with a ratchet stop. The barrel of this windlass is 18 inches in diameter, and the proportion of the driving to the driven gear is 1 to 3. The two top cross-bars carry a horizontal wrought-iron axle upon which two independent cast-iron guide-pulleys run loosely. The use of the two pulleys is to save time in raising and lowering the rods. To effect this object, the ends of two ropes are led over the pulleys and coiled in contrary directions upon the barrel of the windlass. By this arrangement one of the ropes is always down in readiness to be attached to the rods the moment the offtake has been removed, without the labour of uncoiling it from the windlass. The importance of saving time in all boring operations renders the adoption of the double-pulley arrangement desirable in all cases of deep borings.

For the purpose of raising and lowering the sludger, a pair of traverses, 9 inches × 6 inches, is fixed across from one pair of shear-legs to the other, at a distance of about 8 feet below the top traverses supporting the pulleys. These pieces, which are mortised and keyed into the shear-legs, are intended to carry another and a smaller pulley, mounted on a cast-iron frame capable of motion between horizontal wooden slides provided for the purpose and fixed upon the traverses. The slides are made to project beyond the shear-legs, and are furnished with a roller, as shown in the figures, for the purpose of carrying the rope out clear of the frame. The end of the rope, after being led over the pulley and roller, is brought down and wound upon a smaller windlass fixed upon the shear-legs opposite those carrying the larger windlass. The sludging windlass is provided with a brake, to regulate the descent of the tool, as before described; and it may be remarked here that such brakes should be self-acting, the power being obtained preferably by means of a weight. The rope used for the sludger will be $\frac{3}{4}$ inch or 1 inch in diameter, according to the dimensions of the tool. Hempen rope is usually employed, but aloe fibre, allowing of smaller dimensions, has often been used with advantage.

Sometimes, especially when the boring is expected to occupy a long time, the boring frame is made to cover a larger surface of ground, and is boarded in, with the exception of the necessary openings, for the purpose of protecting the workmen from the weather.

Next to the boring frame, the most important part of the head-gear is the oscillating or "rocking" lever. It is by means of this lever that the requisite motion is communicated to the rods when working the cutting tools. It consists of a piece of straight-grained ash, provided with an iron axle, upon which it turns as a fulcrum. This axle is supported upon a wooden framing, composed of four upright pieces, fixed at the bottom in two cross timbers, inserted for that purpose in the framing of the shear-legs, and connected in pairs at the top by two cross-pieces, into which they are mortised. The two inner upright pieces are connected in the same way, to afford a support for the lever axle. Sometimes, however, this axle is supported in the middle of the framing, as shown in Fig. 198; but that arrangement is not to be recommended. The height of the support thus

obtained is about 5 feet 6 inches. The dimensions of the lever will be determined by the weight of the rods, and will therefore vary with the depth of the bore-hole. The same conditions will determine the proportions of the iron axle and its attachments. This axle is fixed upon the lower side of the lever by means of straps and bolts, in the manner shown in Figs. 202 and 203, Plate XVII., an iron carriage being bolted down to the framing to carry the axle. As these parts will be subjected to severe strains, the materials should be of good quality and the dimensions ample. The proportion of the shorter to the longer arm of the lever will be determined by the weight of the rods and the length of the stroke. One to four and one to five are the usual proportions; but in some instances as much as one to nine has been adopted. The total length of the lever will depend somewhat upon the proportion of the arms, but in most cases from 10 to 12 feet will be found to be a convenient length. And with a proportion of one to four, or one to five, and a bore-hole of considerable depth, say from 500 to 700 feet, a scantling of 9 inches × 7 inches will be sufficient. The diameter of the axle in such a case should be $2\frac{1}{4}$ inches.

The length of the stroke should, as far as is practicable, be proportioned to the hardness of the rock which is being bored through. For moderately soft clay, 6 inches may be sufficient; but compact limestone may require 24 inches or even more.

To allow several men to work at the end of the longer arm of the lever, a cross-bar of suitable dimensions is affixed to it. This cross-bar should be of tough ash, of circular section, and of such a diameter as to be conveniently grasped by the hand; it should be fixed, by means of iron straps, upon the upper or upon the lower side of the lever, and never passed through it or notched into it. Instead of the cross-bar, straps of iron provided with a hook at each end may be fixed across the upper side of the lever, leaving the hook projecting over the edge. Short pieces of rope with a ring on one end, and a piece of wood, of circular section and about 8 inches in length, on the other end, may then be used instead of the cross-bar, by placing the ring over the hook and grasping the piece of wood to pull by. In this way four men can work with two hooks on each side, or six men with three hooks. One advantage gained by this method of working the lever is the directness of the strain. With the cross-bar, a preponderance of force on one side—and such a preponderance must always exist, since the men will never be exactly equal in strength—produces a torsional strain great in proportion to the amount of the preponderating force and the leverage of the cross-bar. To steady the lever, the longer arm is sometimes made to move between guides.

The head of the lever should be formed of a sector of a circle, the centre of which is the point of support. This is needed to raise and lower the rods in a straight line. Usually this sector-head is of cast iron, as shown in Fig. 198, Plate XVI. Above the head a stout hook is firmly fixed by means of bolts. To this hook the rods are hung by one of the devices already described, a short piece of chain, or preferably of flat hempen rope, furnished with a ring at one end, and a swivel-head and hook at the other, being required when the lengthening stirrup is used. As the head of the lever partly overhangs the bore-hole, the axle must be so set in its bearings that the lever may be withdrawn when it becomes necessary to use the sludger. The usual manner of providing for this requirement is shown in Fig. 202, where the construction of the carriage allows the lever to be readily lifted off its bearings.

The weight of the rods is constantly increasing as the boring progresses in depth, and, consequently, the force required to work the lever must be constantly augmented in a like proportion. This entails an increased expenditure of labour and money without any compensating gain, for when

a sufficient weight of rods is obtained to give a certain force to the blow, nothing is gained by increasing that force, while great risk of fracture is incurred. When the sliding joint is employed, it is obvious that no increase of weight in the rods can influence the power of the blow in any degree. For these reasons, when the weight of the rods has become sufficient, a counterweight is suspended from a hook at the extremity of the longer arm of the lever, which counterweight is gradually added to as the length of the rods increases. By this means, the force requisite to work the lever is within certain limits kept constant.

It has already been remarked that when the sliding joint is used an elastic stop is provided at surface, to arrest the descent of the rods within the limits allowed by the extent of the slide. Such a stop may be constructed in various ways. The spring pole is perhaps the most suitable, as it is certainly the most simple. The pole should be fixed upon the ground parallel with the surface, and care should be taken so to determine its dimensions that it may not be strained up to near the limits of its resistance, for fracture of the pole would probably occasion fracture of the rods. For the same reason, the rope or chain by which the lever is attached to the pole should be of ample strength. Another matter demanding attention is the extent of the motion allowed by the elasticity of the pole. This extent must be somewhat less than that allowed by the sliding joint in the lower end of the rods, and sufficient precaution should be taken that the limit be not exceeded by the stretching of the rope or the loosening of the pole. Instead of the pole, a very good spring may be made of fir boards $\frac{3}{4}$ inch thick and about 9 inches broad, placed one upon another in such a manner that the bottom one shall extend beyond or overlap the second by 8 inches; the second overlap the third by the same distance, and so on. These boards must be firmly fixed to the ground, and the end of the lever attached by a chain or rope to the end of the bottom board, which must be provided for that purpose with a stout iron hook, securely fixed to the under side with iron straps.

For the purpose of enabling the master borer to ascertain the number of blows made with the cutting tool during a shift or in any given time, a stroke counter is sometimes placed upon the axle of the lever. Such an instrument would be a highly desirable one if it could be constructed in such a way as not to impede the ready withdrawal of the lever from its bearing carriage.

Steam power may sometimes be advantageously substituted for hand labour to work the rocking lever. In such a case, the most simple method of depressing the longer arm of the lever—which may then be to the shorter in the proportion of 2 to 1, or $1\frac{1}{2}$ to 1, or the two may be equal—is by means of cams fixed upon a horizontal axle, supported on a strong frame similar to that for the lever, and turned by a spur-wheel of 5 or 6 feet diameter, driven by a pinion. The engine should be of the portable class, and it should be made to work the windlasses when the lever is not in action.

An essential part of the surface apparatus is the bore-hole guide-tube, shown in Fig. 198, Plate XVI., and Fig. 201, Plate XVII., the latter being a plan of the former to a larger scale. This tube is of wood, and for bore-holes of ordinary dimensions is about 12 inches in diameter and 6 feet in length. The diameter of the bore of this tube is the same as that of the bore-hole, so that the thickness of the wood is about $4\frac{1}{2}$ inches for a 3-inch hole. It is to be inserted in the bore-hole, in a manner to be described hereafter, to a depth that will leave about 10 inches of its length above the surface of the ground, and firmly held in its position by four pieces of timber 9 inches $\times$ 6 inches in section. These pieces are laid upon the ground in pairs, one piece on each side of the tube, the pairs being at right angles to each other. The ends of the pieces forming each pair are then pressed partially together, to make them tightly clasp the tube, and are held in a state of tension by iron straps across

the ends, and these ends are firmly fixed to the ground. Sometimes they are fixed to the framing in which the shear-legs are set; but this practice is not to be recommended, as the vibration of the framing tends to produce injurious effects. When a staple is sunk, they are, of course, set at the bottom of the staple. Various means of fixing these timbers may be employed, the only necessary condition being that there shall be no liability of their becoming loose during the progress of the work. The upper surfaces of these timbers are an inch below the top of the tube. The aperture of the tube is provided with a pair of iron shutters, opening and closing horizontally, as shown in Fig. 201. The form of these shutters and the mode of fixing them will be clearly seen from the figure. Each shutter is notched to form a square aperture of $1\frac{1}{8}$ inch side through which the rods may freely move from joint to joint when the shutters are closed. The use of these shutters is to prevent anything from falling down the bore-hole. Instead of this kind, flap shutters may be used. These consist of two semicircular iron discs hinged upon the tube, and opening vertically like a clock-valve, a notch in each forming the aperture for the rods, as in the preceding kind.

The top length of the rods terminates, as previously described, in a swivel-head, by which it is suspended from the rocking lever. For the purpose of adjusting the height of the head to the requirements of the lever, several short lengths are needed, varying from one foot to three feet, which are screwed on as the boring progresses, the shorter lengths being removed and a longer one substituted at each change. These lengthening pieces, one of which is represented in Fig. 204, are all provided with a screwed socket. Sometimes they are furnished with an eye through the shank just below the head, through which a piece of wood is passed to form a lever, by means of which the rods are turned round during the operation of boring. This arrangement, shown in Fig. 205, is common in Belgium, but in England it is more usual to employ the brace-head or tiller for this purpose.

The tiller may be of wood or of iron. When of wood, it consists of a piece of ash, 4 inches in diameter, square in section in the middle, and rounded off and reduced in size towards the end, as shown in Fig. 206. The middle portion is provided with a notch one inch square to receive the rod, one side of the notch being formed by an iron plate turning on a bolt at one end and fixed at the other by a screw. On withdrawing this screw, the plate drops and leaves the notch open. Another screw through the centre of the plate is provided for the purpose of fixing the tiller upon the rods. When the tiller is of iron, it is constructed in the manner shown in Figs. 207 and 208. It consists of two portions, each 18 inches or 2 feet in length, joined by two screws. To apply the tiller to the rods, the two portions are separated by withdrawing the screws, and the portions are applied one on each side of the rod, and fixed in that position by reinserting and tightening the screws. Or, when the rods are not suspended from the lever, this tiller may be applied by passing it over the head of the upper length. The ends of the tiller are turned up, as shown in the figure, to afford a convenient hold for the workmen.

For the purpose of raising and lowering the rods, "lifting dogs" are required. These consist of a claw-hook, through the shank of which a ring is passed, by means of which it is attached to the rope. When in use, the claw is placed under the head or the shoulder of the top length of rod, and the latter hauled up or lowered by means of the windlass. The lifting dog is represented in Figs. 209 and 210.

Another instrument required for raising or lowering is the "nipping fork," or "tiger." When the rods have been hauled up as far as the height of the shear-legs will allow, they must be supported in that position while being unscrewed. For this purpose, the nipping fork, represented in

Fig. 211, is placed upon the top of the guide-tube beneath the joint in the rod, and the latter lowered till the joint rests upon the fork. In like manner, in lowering, the rods are let down till the lifting dog rests upon the fork; the next offtake is then screwed on, and the lifting dog hanging from the other pulley placed under the shoulder of the top length, and the rods slightly lifted, thereby to allow the lower dog to be removed. When only one lifting dog is used, after the first offtake has been removed, a short swivel-head lengthening piece must be screwed on to each subsequent offtake, to afford a hold for the dog. Provided the shutters of the guide-tube be made sufficiently strong, they may be made to fulfil the purpose of the nipping fork.

For the purpose of screwing up and disconnecting the rods, a kind of wrench, called a "hand-dog," is required. This instrument is shown in Fig. 212, from which its construction will be understood without description.

Extracting Tools.—The shocks to which the rods are necessarily subjected occasion a change among the constituent molecules of the iron, the fibrous structure being gradually converted into a crystalline one. This change renders the iron brittle, and as the weight of the rods increases as the boring progresses, the danger of fracture becomes rapidly greater as the work proceeds. The screw-joints also become loose from the same cause, and liable to yield. Moreover, the vibrations become greater as the length and weight of the rods increase, and these vibrations tend not only to knock down the sides of the bore-hole, but to cause a rupture of the rods. To these inevitable sources of danger must be added another and a much more prolific one, namely, the negligence of the workmen. Very frequently the nipping fork is carelessly placed under the joint, or is as carelessly forced out of its place during the unscrewing of the joint, and, as a consequence, the rods fall back into the bore-hole. Or the same result may follow the negligent placing of the lifting dog beneath the rod-head. Accidents from these causes are lamentably frequent, and they are attended with the worst consequences. When the rods are in this way let fall in the bore-hole, the shock to which they are subjected is most violent, and its effects most destructive. The rods may be fractured in one part and bent in another, and the fragments may be jammed into the sides of the bore-hole. The cutting tool may be fractured, or if nearly through a hard rock resting upon a soft one, it may be driven through and tightly held in the cleft. The concussion may also bring down stones from the sides of the bore-hole, to complicate the consequences and increase the difficulty. Thus it is evident that not only is it necessary to take due precautions to prevent the occurrence of such accidents, but that means must be at all times held in readiness to remedy the evil should the accidents happen. These means consist of tools designed to remove the fragments of the rods or the cutting tool from the bore-hole, and are designated as "extracting tools."

When a portion of the rods has been dropped into the bore-hole, the first thing to be done is to ascertain the form and position of the broken portion. For this purpose a ball of clay is well kneaded with oil and hemp fibres to render it plastic and coherent, and let down on the end of the sludger rope. On being raised to surface, the impression on the soft clay indicates the circumstances which it is required to know, and the borer selects his tool accordingly. When a rupture has occurred accidentally, an inspection of the end of the suspended portion of the rods will show whether they have parted above or below a joint. If the fracture has occurred either in or immediately above a joint, the rod may be seized by an instrument called a "crow's-foot" or "crow," represented in Fig. 213. This instrument, the form of which will be understood without description, is lowered at the end of the rods into the bore-hole, and turned round till it has grasped

the broken rod beneath the joint, when the whole may be raised without difficulty. The first attempt with this instrument is usually successful.

When the fracture has occurred immediately below a joint, or near the middle of a length, the crow's-foot cannot be used, because the long portion above the joint would catch in the side of the bore-hole. In such a case, a tool called a "bell" is employed. There are two kinds of bells used, known respectively as the "screw-bell" and the "box-bell." The former, which is represented in Fig. 214, consists of a frustrum of a hollow cone, provided on the inside with a steeled screw-thread. The lower portion is larger in diameter, and the upper portion smaller in diameter, than the diagonal of the rods. Upon its lower edge, a piece of thin plate iron is fixed, to form a kind of funnel-shaped continuation, the use of which is to guide the end of the rod into the bell. When the bell has been dropped over the rod, the former, which should be well greased on the inside before being let down, is turned slowly round until the thread has sufficiently bitten the rod to allow it to be lifted. It is hardly necessary to remark that the bell must be turned in the direction that will not disconnect the joints.

The box-bell, Fig. 215, is similar in form to the preceding; but, instead of the screw-thread, it is provided on its upper side with two iron catches opening upwards. The aperture through the bell is, in this case, greater than the diagonal of the rods, and the distance between the ends of the catches when down is slightly less than the length of the side. The bell being dropped over the end of the rod, the latter passes through by raising the catches; but when the bell is raised, these catches grip the rod, and by this means it is brought to surface with the bell.

Instead of the bell, the wad-hook, or spiral worm, shown in Fig. 216, Plate XVIII., is frequently employed. This hook is attached to the end of the rods, and lowered as far as the broken portion, when it is turned round till it has taken a firm hold of the rod. This tool is a very effective one. The form shown in Fig. 168, Plate XIII., may also be employed for the same purpose. These tools may be used to extract a broken chisel, or anything that may have been accidentally dropped into the bore-hole. Numerous forms of extracting tools have been proposed; but the foregoing are sufficient for every case that is likely to occur, and they possess the merit of simplicity.

Tubing.—When a bed of soft clay or loose sand is passed through, a difficulty arises from the swelling of the bed. The pressure of the superincumbent rocks forces the soft material out into the vacant space made by the boring, and so tends to stop up the bore-hole. The swelling of the bed is indicated by the friction of the cutting tool against the sides on raising and lowering it; and when this friction is remarked, no time should be lost in remedying the evil which, having begun, tends to increase rapidly. The means employed to combat this evil consist in lining the bore-hole with iron tubes. These tubes are provided with screwed plug and socket for joining in the same manner as the rods, and they are usually in 10-feet lengths. Other forms of joint are used, but the screw joint, though somewhat more expensive, is always to be preferred. An example of a lining tube is shown in Fig. 217, Plate XVIII.

A regulating tool having been put down to enlarge the bore-hole at the part which has begun to close in, a length of pipe of the same outside diameter as the bore-hole, and having its lower edge steeled and sharpened, is inserted in the hole and driven down till its socket is nearly level with the top guide-tube. Another length is then screwed on, by means of the pipe-clamp, represented in Fig. 220, and driven down in a like manner. This is continued till the clay or sand-beds are passed, when the boring may be again resumed. As, however, the cutting tools will have to pass

through the pipes, it is obvious that the hole must be continued of a smaller diameter. Should other soft beds be subsequently met with, additional lengths of tubing will be screwed on, and driven down to the swelling rock. But a limit to this proceeding is soon reached. The friction of the running material against the tubes is sufficient in most cases to prevent a much greater length than 100 feet from being driven. When this limit has been reached, another set of tubes, having an outside diameter equal to the inside diameter of the first, is driven down within the first lining, and the same thing must be repeated for greater depths. Inserted in this way, the lining of a bore-hole appears like the several slides of a telescope when drawn out. An example is shown in Fig. 218.

As the diameter of the bore-hole is considerably reduced by each set of lining tubes inserted in this manner, it should be sufficiently large at the commencement to allow of these successive reductions without diminishing the bore-hole, at the depth to which it is proposed to carry it, to impracticable or undesirable dimensions. In undertaking a boring, the necessity for lining the hole should always be anticipated, for though in many cases the whole of the beds passed through will be of a sufficiently resistant character to stand, the possibility of meeting with unstable rocks always exists. When the soft bed occurs within a moderate distance from the surface, it will be prudent, unless the character of the strata beneath is well known, to enlarge the bore-hole from surface before putting in the lining tubes. When the hole has been enlarged in this manner, or when only the contracted portion has been rebored to its original dimensions, no time should be lost in getting the tubes down; for when a bed once begins to run, the motion, however slow it may be, is continuous. So in boring through a soft bed, the operations should be pushed on with all possible speed, and the tubing driven down before the swelling begins. This is one of the questions to which the master borer will be required to direct particular attention.

Appliances for Driving Tubes.—The operation of forcing the tubes down the bore-hole is one demanding great care. Proper provision must be made for keeping the tubes perfectly vertical during the driving, to avoid the danger of fracture arising from transverse strains and indirect shocks. The driving is effected either by blows or by pressure. When the former method is adopted, a block of wood bound with an iron hoop to prevent crushing, and having a hole through the centre sufficiently large to allow the free passage of the rods, is placed upon the socket of the upper length of tubing to receive the blow; the object being to prevent fracture of the tube by interposing an elastic medium between it and the instrument with which the blow is given. The latter consists of another block of wood bored and bound in the same manner as the first, and constituting a kind of "monkey," to be used as in pile-driving. This monkey is fixed by pressure-screws upon an upper length of rod, as shown in Fig. 219. Several lengths of rod are then screwed on to give weight, and passed through the hole in the lower block, and allowed to hang down the tube and bore-hole. A rope is then attached to the head of the rod, carried over the pulley at the top of the shear-legs, the ordinary rope having been lifted off for the occasion, and wound with one turn upon the windlass. Frequently it will be found convenient to use the sludger pulleys and windlass for this purpose. To work the monkey, two men turn the windlass, a third man holding the end sufficiently taut to enable the former, by means of the friction, to raise the rods with the monkey attached. The drop is occasioned by releasing the end of the rope. The descent of the tubes may be assisted by giving them a partial turn after each blow by means of the clamp-lever, represented in Fig. 220.

Sometimes, when the depth has become great, and the blows, by reason of the vibrations, insuf-

ficiently effective or dangerous, recourse is had to pressure. A very simple and efficient appliance of the character required in such a case is represented in Fig. 221. Two stout balks of timber, designed to furnish the points of support, are firmly fixed to the ground by being passed beneath the framing of the shear-legs, and otherwise held down if additional resistance is necessary. Into these balks are fixed vertical iron or steel rods, upon which a screw-thread is cut nearly throughout their length. The upper ends of these rods pass through a stout wooden block provided with a central aperture sufficiently large to allow free passage to the tube, and are each furnished with a broad washer and a nut. Into the block two other vertical rods are fixed; these terminate upward in an iron collar resting upon and encircling the socket of the tube. The latter rods are of the same length as the former, and all are jointed in the manner shown in the figure. The nuts above the block and upon the lower rods being turned by keys affording a sufficient leverage, the tube is pressed down into the bore-hole. Care must be taken to give each nut the same amount of turn, to keep the strains direct and equal.

Tools for Extracting Tubes.—When the bore-hole has been completed, and the end for which it was undertaken attained, it becomes desirable to recover the tubes used to line the hole. Also when more sets of tubes are required than anticipated, and the diameter of the bore-hole has consequently been so reduced that farther progress is impracticable, it becomes necessary to withdraw the lining and to enlarge the hole from surface. The operation of withdrawing the tubes is always a difficult one, and when the hole is deep is seldom altogether successful. But in most cases a large proportion of the tubing may be recovered if suitable means are employed. These means consist of tools for disconnecting and lifting the several lengths of tubing, or for lifting them altogether.

Of the former kind, the simplest and most effective is the screw-plug. This instrument consists of a conical plug having its lower end slightly less in diameter than the bore of the tube, and its upper end slightly greater, and provided with a left-handed steeled screw-thread. This plug terminates upward in a shank and screw-socket for the purpose of fixing it to the rods. The latter, which are constructed specially for this purpose, are of large section, and are connected by left-handed screw-joints. The screw-plug is lowered at the end of these rods into the end of the tube, and turned slowly round till the thread has bitten. When the plug has obtained a firm hold of the tube, the latter will be unscrewed by the continued left-handed motion of the former, and may be lifted by it. The same operation is repeated for each length of tubing.

Of the tools designed to lift the whole length of tubing, the best is that known as "Kind's plug," from its having been first employed by Kind. It consists of a block of oak of an ovoid form fixed upon the end of an iron rod. This rod passes through the centre of the plug, which it holds by means of a nut, and terminates upwards in a screw-plug for the purpose of attaching it to the ordinary boring rods, as shown in Fig. 222. The diameter of this wooden plug at its largest part is slightly less than that of the tube, so that a little amount of play is allowed between it and the sides of the tube. When it is required to raise the tubes, the plug is lowered to the desired depth, and one or two shovelfuls of coarse, gravelly sand, washed and sifted, are thrown down upon it. This sand fills the space between the sides of the tubing and the plug, and the latter is thereby firmly wedged in. The rods being then hauled up, the tubing is raised with them. If it be desired to make the plug leave go its hold on the tube, it is only necessary to lower it below the lining, when the sand will run out.

When the tubing is too firmly held by the friction against the sides of the bore-hole to allow of

it being raised altogether, and it is deemed undesirable to have recourse to the special rods required for the screw-plug, Kind's plug may be used in conjunction with another kind of tool to raise the tubing in portions. The use of the latter tool is to cut through the lining so as to divide it into portions capable of being raised at once. Numerous forms of tools have been invented for this purpose. One of the simplest of these, and the most certain in its effects, is that represented in Fig. 223. By suspending this tool at a requisite and fixed height in the bore-hole, on the end of the boring rods, and turning it round, the cutting edge, which is pressed by a spring against the sides of the hole, cuts through the lining, the severed portions of which may then be raised by Kind's plug in the manner described above. The cutter is so constructed that it may be readily withdrawn from the cut and raised to surface.

The Operations of Boring.—The foregoing descriptions and illustrations are intended to give a clear and full understanding of the nature, form, and use of the various tools and other appliances required in boring. It now remains to take a connected view of the operations, from the preliminary arrangements to the completion of the undertaking.

The first duty of the engineer is to choose a suitable site for the boring, and in this choice he will be guided mainly by considerations of convenience. The *locality* will, indeed, be determined by the indications furnished by the geological survey; but the particular spot in that locality will be selected in accordance with other conditions of a wholly practical character. The consideration of these conditions will demand knowledge, forethought, and a sound judgment. A primary object is to reach the seam with the least possible expenditure of labour and material. The engineer will, therefore, seize any opportunity that may offer itself of abridging the depth of the bore-hole. To this end, he will prefer a hollow to an eminence as a site on which to commence the boring. By this means several yards may often be saved in depth; and it must be borne in mind that the cost saved thereby is that of an equal length at the bottom of the bore-hole, the importance of which saving will be understood when the mode of calculating the cost of boring is considered. But though the lowest surface is the most advantageous in this respect, a grave error might be committed in selecting it without reference to other circumstances. Such a surface may be composed to a considerable depth of alluvial soil, incapable of standing without support, and full of water. Or it may be subject to inundation in times of heavy rains. Any one of these circumstances would entail greater expense than that saved by the reduction of depth, besides occasioning a risk of total failure. In addition to these considerations, and others which will occur peculiar to each locality, that of facility of access will require the bore-hole to be located near a road. Of course, in a question of mere convenience like this one, much liberty exists; but as all the materials will have to be carried to the spot, and as easy means of access must be provided for the workmen, who will require to make daily use of the approach during several months at the least, the desirability of choosing a spot in the neighbourhood of a highway will be apparent.

When a suitable spot for the boring has been selected, and a passable road provided to it from the highway, the operations are begun by sinking a pit five or six feet in diameter, called a staple, down to the solid rock. The staple has two important uses; the first of which is to remove the surface soil and loose rock so as to allow the boring to be started in the solid rock; and the second, to increase the length of the offtake by augmenting the height of the lift. The cost of sinking the staple is fully compensated by the consequent reduction of the depth of the boring, which reduction, as before remarked, must be valued according to the cost of the last ten yards of the boring.

Sometimes the staple is omitted, and the boring commenced from the surface; but the advantages afforded by it are sufficient to render its adoption desirable in all cases. When sunk to the required depth, the staple is lined, either with poling boards and curbs, or with bricks set dry.

From the bottom of the staple a hole is dug to a depth that will leave the guide-tube projecting about ten inches or a foot when placed vertically in it. This tube is carefully plumbed, and fixed in its position by filling in and firmly ramming the earth around it. It is of the utmost importance that the tube should stand exactly vertical, as it is to act as a guide to the direction of the bore-hole, and too much care therefore cannot be expended in fixing this tube. The cross-timbers for holding and guarding the top of the tube are next placed in the manner already described.

When the guide-tube has been fixed in its position and provided with its shutters, a floor of planking must be constructed for the workmen who guide the boring. This floor is sometimes supported upon the timbers holding the guide-tube; but as such an arrangement tends to loosen the tube by the constant jarring of the floor, it is better to introduce other and independent supports.

While the foregoing operations are in progress, the erection of the shear-legs, or boring frame, should be proceeded with. The form and dimensions of this apparatus will be mainly determined by the depth of the boring. In every case, however, unless the boring be one of small importance, provision should be made for two pulleys for raising and lowering the rods, and other pulleys for the sludger-rope. In fixing these pulleys, it is of the highest importance to bring the periphery of the wheel into such a situation over the guide-tube that the centre of the rope shall coincide with the centre of the bore-hole when hanging vertically. If these simple matters are neglected, the consequences are often very prejudicial to the success of the undertaking, and as a matter of fact, they are frequently neglected on account of their simplicity, attention being directed to things of apparently greater importance. These remarks apply with still greater force to the erection of the rocking lever, from which the rods are suspended when in use.

Besides the boring frame, certain surface erections will be required for all important borings. These are a small smithy, a shed for the protection of the workmen, and a hut for the man in charge of the boring. Of course, these erections will be of a slight and altogether temporary character.

When the whole of the apparatus and materials have been provided and placed in their respective positions, the number of workmen required must be determined and the duties of each assigned to him. Probably in no part of the undertaking will the sagacity of the engineer, or whosoever else acts as chief, be called into action so much as in this. Whenever a number of workmen are brought together, there is one whose constitution both of mind and body renders him better capable of performing certain duties than the rest. To recognize these characteristic qualities in each of the men assembled under him, and to assign to each the work which he is best able to perform, are thus duties of the engineer, the importance of which can hardly be over-estimated when it is borne in mind that the success of a boring depends very much upon the several operations being performed in an intelligent and a careful manner. A sufficient number of men should always be provided, since delays are above all things to be avoided; for not only are some of the men kept idle by delays, but, which is of graver consequence, the bore-hole may be exposed to danger from the swelling of the strata. On the other hand, too great a number of men cause delay by getting into each other's way.

When everything has been prepared, the boring will be commenced by screwing a short

length of rod with swivel-head upon the cutting tool, and lowering it into the guard-tube. The rod will then be suspended to the lever by means of the stirrup, or whatever other connection has been provided, the tiller affixed to the rod, and the shutters of the tube closed to guard the bore-hole. In commencing operations, the weight of the cutting tool and rod will be insufficient to perform the work required, and therefore a weight will have to be hung upon the shorter end of the lever. As the rock at starting will probably be soft, only light blows will be needed till some degree of depth has been attained, when the constantly increasing length of the rods will furnish the requisite weight. The cutting tool must, of course, be chosen according to the nature of the stratum to be pierced. Thus at the commencement, when the rock is soft, the shell-auger will probably be the most suitable tool; and the same, or the clay-auger, will be required whenever a soft stratum is met with. When a hard rock is reached, the chisel will be substituted for these tools. The length of the stroke will also be determined by the hardness of the rock. This matter should be left entirely to the master borer, who will direct the length of stroke in accordance with the indications which he is observing. Under no pretence whatever should the men who work the lever be allowed to alter the stroke at their discretion. The limits within which the stroke may be varied may be stated generally as 6 inches and 26 inches.

To work the lever, the men chosen for that duty seize the cross-bar on the end of the lever, or the ropes used instead of the cross-bar, as previously described, and pull it down with an even motion: a jerky motion being very objectionable. They then suddenly release their hold, thereby allowing the rods to fall back into the bore-hole. The number of strokes made is generally about 18 or 20 a minute. While the rods are being raised, a man upon the floor or platform at the bottom of the staple turns them partially round by means of the tiller, to prevent the cutting tool from falling a second time into the same place. The amount of turn given at each stroke is about one-eighth of a revolution; this amount should, however, be varied slightly. The man appointed to this important duty should possess intelligence and a sense of the responsibility resting upon him. Frequently the master borer undertakes this duty himself. An experienced man can judge very accurately of the nature of the stratum which is being passed through, by the character of the shock transmitted through the rods. And thus at every change he is able to direct the length of the stroke in accordance with it, or to order a change of tool, if that be necessary.

The time during which these operations are continued, as well as the depth by which the bore-hole is advanced by them, will depend upon the character of the rock. When the rock is only moderately hard, the chisel may penetrate six inches or even more before it will need resharpening; when the rock is very hard, two inches, or even less, will be sufficient to blunt the edge. As soon as the bore-master deems it necessary to raise the tool for the purpose of replacing it by another, he orders the men at the lever to cease. These then place themselves at the windlass, and the man at the bottom of the staple, being provided with a key, detaches the rods from the lever connection, and places the lifting dog beneath the head. This operation, simple as it is, requires very great care, for if the rods are allowed to fall, immense and perhaps irreparable damage may be caused. The men at the windlass having raised the rods to the height of the shear-legs, the man in the staple places the other lifting dog under the lower joint in the rods, which joint will then be a little above the guide-tube, and calls out to the former to lower. The rods are then let gently back till the second lifting dog rests upon the guide-tube shutters, and the man with his key then unscrews the joint. The offtake, that is, the portion of the rods removed, is then hung up, a kind of rack being provided

upon the shear-legs for that purpose. Sometimes the offtakes are stood up, or laid down; but it is far better to suspend them, for by that means the joints are kept free from dirt, and the rods are protected from transverse strains. As soon as the offtake is detached, the men at the windlass again wind up the rods to the top of the shear-legs, and the same operations are repeated. This is continued till the whole of the rods have been raised.

As the greater part of the time occupied in sinking a bore-hole is taken up by raising and lowering the rods, every arrangement should be made to facilitate and expedite these operations. And not only is this desirable for the purpose of economizing labour, but in boring through a soft stratum, such as plastic clay, for example, success is often to be gained only by rapidity of execution; for it is essential that the retaining tubes should be got into their place before the stratum begins to swell.

When the cutting tool has been removed from the bore-hole, the sludger is immediately put into operation. For this purpose the lower pulley is run out over the bore-hole, and the sludger let down with all possible speed. Its descent is checked, as previously described, by means of a brake. In the case of a hole 1000 feet deep, the time required for the descent of the sludger is about $3\frac{1}{2}$ minutes. The operation of "pumping" the sludger is then begun and continued for about 4 or 5 minutes; after which the instrument with its contents is raised by means of the windlass provided for that purpose. The time occupied in raising the sludger will be, for the afore-mentioned depth, from 12 to 15 minutes.

While the operations of sludging have been going on, the worn cutting tool has been removed from the rods, and a fresh one, after undergoing the proper tests, substituted for it. As soon as the sludger has been withdrawn, the upper lifting dog hanging from the pulley is placed under the upper joint of the offtake, to which the cutting tool is attached, and lowered by means of the windlass till the dog rests upon the closed shutters of the guide-tube. Another offtake is then screwed on, the other lifting dog placed under the upper joint or socket, the rods are slightly lifted by it to free the lower dog, and then lowered till the other dog rests upon the shutters. These operations are repeated till the whole of the rods have been lowered.

It will be remarked that by using the guide-shutters instead of a nippingfork, in the manner described, the necessity for screwing on a short length of rod, or topit, at each lift is removed and much time saved. When intended for this use, the shutters are made sufficiently strong to take the weight of the rods, and the aperture through them of such form and dimensions that when closed they shall grip the rods like a key. To keep them securely closed while the joint is being unscrewed, a hook fixed upon one shutter is dropped into the outer eye on the other. During the operations of boring, this hook is set into the inner eye for the purpose of holding the shutters partially open to allow of the rods being turned.

When, in the course of the boring, a weak clay stratum is met with that will evidently not stand long unsupported, the operations should be pressed forward with all possible speed, and continued by night as well as by day without intermission till the stratum has been passed. As soon as strong ground has been reached, the boring operations should be suspended and every exertion directed to get the retaining tubes down before the stratum begins to swell. These tubes, with the appliances for driving them, should be always in readiness; for though they may never be required, if the necessity for them does occur, and they are not at hand, the consequences of waiting till they can be procured may be very serious. In this matter, delays are especially

dangerous. When the tubes have been got down beyond the dangerous portion, the boring may be resumed.

A stratum of running sand will often occasion considerable difficulty. The progress made by the ordinary means is in such cases extremely slow, and the final result seldom satisfactory. Frequently, indeed, it is impossible to pass through such a stratum, especially when it contains much water, with the common boring tools, and it therefore becomes necessary to have recourse to other and more appropriate means. Generally the most effective of these extraordinary appliances is a jet of water. The simplest and most satisfactory method of sinking by means of the water-jet is as follows: A lining of tubes is put down the bore-hole till the sand stratum is reached. A tube —which may be of metal with screw joints, or of flexible material—provided with a pointed metal nozzle, pierced laterally with several holes, is then let down inside the lining till the nozzle rests upon the sand, and the other end at surface is placed in communication with a force-pump. An ordinary fire-engine is very suitable for this purpose. Water being forced down the tube, the sand is stirred up at the bottom of the bore-hole, and raised to surface in the annular space between the tube and the lining. During the operation pressure is kept upon the latter to sink it as the sand is removed. The nozzle of the water tube must, of course, be lowered as the sinking progresses. In this way the sand may be passed very quickly. On firm ground being reached, the lining should be driven hard down into it to prevent the running sand from escaping beneath the tubes, after which the boring may be resumed by the ordinary means. It may be remarked here respecting the operation of lowering lining tubes, that each length of tube should be numbered, and marked with its exact length in feet and inches; and that, as each fresh length is screwed on, its number and dimensions should be plainly entered in a memorandum-book by the master borer. If these matters be neglected, there will soon be uncertainty as to the exact depth to which the lining has been driven.

Accidents, which in spite of every precaution will in general be frequent, will call forth the ingenuity of the engineer, and test his resources to the utmost. He will, however, do better in displaying his skill and forethought in devising means for preventing the occurrence of accidents, than for remedying the mischief after they have happened. In directing the operations of boring, he cannot take too many precautions or show himself too careful, for he should remember that his example will influence the men under his orders. One of the worst accidents that can happen, and one that unhappily is not of rare occurrence, is the falling back of the rods into the bore-hole while they are being raised or lowered. Such an accident may be prevented by proper care in placing the lifting dog and the guide-shutters or nipping fork. Another bad accident is the closing in of the bore-hole upon the cutting tool. The precautions to be taken in this case consist in boring through a dangerous stratum as rapidly as possible, and in lining the hole immediately the stratum has been passed. The means for extracting broken rods have already been described. Sometimes a tool will become jammed in a cleft of the rock at the bottom of the bore-hole. In such a case, force should be applied to the rods gently rather than in a violent and jerking manner, for such a manner would be likely to fracture the joints. If the tool is very firmly held, a succession of light blows will loosen it when violent wrenching fails. To lessen the risk of the rods being fractured and becoming jammed in the bore-hole when accidentally dropped, a device called a "parachute" is sometimes employed. This consists of a thick leather washer affixed to the rods towards the lower extremity. This washer has a diameter equal to about two-thirds of that of the bore-hole, and is allowed to

move up and down upon the rod between two stops set at a distance apart somewhat greater than that required by the longest stroke. When in use, the rod passes freely through the washer, the motion of which is impeded by the water in the bore-hole. Should the rods fall, the upper stop catches the washer, and the resistance of the water, which is forced to escape between the edges of the washer and the sides of the bore-hole, then causes the rods to fall gently to the bottom. The washer offers but little resistance to the raising and lowering of the rods, the motion of the windlass being comparatively slow. Accidents are frequently caused by iron bolts and nuts being dropped into the bore-hole. To prevent this the guard-shutters should be kept constantly closed. Sometimes these obstructions, and others of a like character, as fragments of a tool or a pebble, cannot be seized by the common extracting tools. In such a case they may often be raised by a simple expedient. A lump of clay moistened with oil to make it soft, and mixed with hemp fibre to give it cohesion, is fixed into the bottom of the sludger below the valve. The sludger is then lowered to the bottom of the bore-hole, upon which it is struck lightly two or three times. The obstruction is pressed into the clay, to which it adheres with sufficient firmness to allow of its being raised with the sludger. Numerous other minor accidents will frequently occur which could not be foreseen; the remedy for these must be left to the ingenuity of the engineer in charge.

We have already described the difficulties presented by a stratum of running sand, and shown the necessity of lining such portions of the bore-hole. Cases may, however, occur in which this necessity can be obviated. In prospecting for minerals, when the bore-hole is not required to stand after the boring has been completed, if the sand stratum is a thin one, and free from water under pressure, it may be retained in the following manner: As soon as the stratum has been passed, the cutting tool is withdrawn, and a sufficient quantity of plastic clay thrown down to fill the bore-hole to a height a little above the stratum. This clay is then rammed firmly down by means of a suitable instrument at the end of the sludger rope, for the purpose of rendering it compact and forcing it into the hollow sides of the bore-hole formed by the escape of the sand during the boring. The clay is then bored through by means of the clay-auger, leaving a lining of that material to support the sand. Whenever practicable, this simple expedient should be adopted, for it not only saves the cost of tubing from surface, but it allows the bore-hole to be continued of the same diameter.

Occasionally, when the strata are highly inclined, and composed of alternating hard and soft beds, the bore-hole will deviate from the vertical. In such a case, the defect has been remedied by filling up the hole, to the point at which the deviation commenced, with flint pebbles, and after having rammed them firm, resuming the boring through the hard mass. When, however, proper care is taken, deviation from the vertical is of very rare occurrence.

The débris brought up from the bottom of the bore-hole by the sludger must be treated with careful attention, for it must be borne in mind that in prospecting for minerals it is to obtain this débris that the boring is undertaken. Being composed of the rock through which the cutting tool is passing, it is evidence of the nature of that rock, and the only evidence of that character that the boring can afford. It is an unfortunate circumstance doubtless that by the ordinary methods of boring the débris is reduced to almost a powder, so finely comminuted, indeed, that it is often designated as *bore-meal.* It is true that a solid core may be obtained by the special tools already described, and such cores should be extracted from every bed passed through; but throughout the greater length of the bore-hole the rock is necessarily broken up into meal. In this state its indications are more or less of a doubtful character, and it therefore becomes necessary to exercise

care and caution to eliminate the sources of error. The débris at the bottom of the bore-hole becomes mixed with the materials from the higher beds, which fall from the sides of the hole during the process of boring. For this reason, that portion which comes from the bottom of the hole, and which, consequently, is situate in the lower end of the sludger, is deserving of more attention than that which is first taken up. Argillaceous materials should be dried; fragments of shale and sandstone should be well washed to remove the mud from them; and when the materials are found to be mixed, that which constitutes the major portion must be taken to represent the rock which is being passed through. A sample of the rock should be preserved whenever a change occurs, and for this purpose a box divided into suitable compartments will be required. The sample, when placed in the compartment, should be numbered, and the number should be entered in a journal. In this journal the character of the rock should be accurately described. The usual descriptions in sections of strata are wholly insufficient and unworthy of the knowledge of the present day. Such expressions as stiff blue clay, hard rock, soft rock, and metal, convey no notion of the actual character of the rock, and can be of no other use than to cloak ignorance. On the other hand, the composition of the rock may be clearly shown by such compound terms as "arenaceous," "calcareous," or "ferruginous clay," "calcareous shale," "bitumino-calcareous shale," "silicious sandstone," argillaceous sandstone," "argillo-calcareous sandstone," and "argillaceous limestone." The contents of the sludger should also be carefully examined for organic remains, and special search for these should be made in the solid cores raised. Such remains are, as previously pointed out, of the highest importance in determining the formations through which the boring is progressing.

General Considerations concerning a Boring.—Enough has already been said to show that boring to great depths is an undertaking demanding great care, skill, and experience. To ensure success, difficulties must be anticipated: it is not sufficient to provide for them when they occur, or even when indications of their approach appear. An immediate remedy may often be efficacious; a tardy remedy is rarely so. To have ready at hand whatever is wanted is to prevent dangers the existence of which may never be suspected. This foresight is everywhere necessary, in the apparently trivial as well as in the visibly important matters, and from the preliminary arrangements till the completion of the undertaking.

In commencing a boring, the initial diameter of the bore-hole demands careful consideration The important point is to begin with a sufficiently large diameter to allow of subsequent reductions by tubing. If anything is known of the strata to be passed through, the diameter will be determined according to the difficulties anticipated. But if the strata be wholly unknown, it will be prudent to assume difficulties, especially if the boring is to be carried to a great depth, and to proportion the initial diameter so as to allow of several reductions. In easy ground, when the boring is expected to attain a great depth, the hole should be commenced with a diameter not less than 8 inches, and this diameter should be increased to 12 inches in difficult ground. The minimum practicable diameter at the bottom of the bore-hole may be taken as 3 inches.

The shear-legs or boring frame should be as high as possible within the limit previously stated, and the height of the lower side of the pulley above the top of the guide-tube should, as before remarked, be a multiple of the lengths of which the rods are made up. Two pulleys should in every case be provided for raising and lowering the rods, and other pulleys for the sludger rope, for by means of such arrangements much time is saved; and it has already been shown that rapidity of execution is often essential to success. Iron rods are preferable to wooden ones in bore-holes

of ordinary dimensions, and the screw-joint should always be employed. When the depth has become considerable, the use of the sliding joint for the cutting tool should be deemed indispensable. Only the simplest tools, such as we have described, will be required; complex forms will rather retard than hasten the progress of the work. Retaining tubes of the diameter of the bore-hole in that portion in which the cutters are at work should be always at hand, together with the means of forcing them down. For depths exceeding 300 yards, it will generally be advantageous to employ steam power to work the lever, and also to raise and lower the rods and the sludger. Besides being in such a case more economical than hand labour, it contributes greatly to the success of the undertaking by hastening the progress of the boring, and by reducing the number of men required to a few experienced and skilled hands. To diminish the risk of accident, the connection between the engine and the machinery should be made by means of a belt.

Journal of the Boring.—Besides the master borer's memorandum-book, in which he will record everything of the slightest importance that occurs, with the time and other details of its occurrence, and the ordinary books in which the hours of labour, the time expended on every operation, and the materials employed are entered; another book, called the 'Journal of the Boring,' should be kept by the engineer in charge. If a boring, which must of necessity be a long and costly operation, be undertaken solely for the purpose of ascertaining the nature of the strata, it is obvious that the journal in which the information so obtained is recorded will demand the most careful attention, and that its value will be proportionate to the attention bestowed upon it, and the fulness with which the information is given. The loose manner in which the journal is frequently kept renders it of little value for the immediate purpose for which it was undertaken, and utterly worthless for the more extended use of determining the geological constitution of the district. Thus full advantage is not taken of the information obtained by a boring upon which much time and money have been ungrudgingly expended. To render it adequate to the requirements demanded of it, the journal should give a full and accurate description of the strata passed through; it should indicate the thickness of each stratum, and its depth from surface; it should show the angle of its dip, and its water-bearing character; it should exhibit to the inquirer the nature and species of the organic remains contained therein; and it should describe the cutting tool employed to penetrate it, and tell the time occupied in passing through it. Other information may profitably be added; but the above mentioned should be considered as indispensable. The following arrangement of the page may be taken as a guide in preparing the journal:

JOURNAL.

Boring executed at in the County of On the Estate of .

Begun May 1, 1874. Completed Nov. 10, 1874.

Date.	Description of Strata.	No. of Specimen in Case.	Thickness.	Depth from Surface.	Angle of Dip.	Diameter of Bore-hole.	Description of Tool employed.	Time actually occupied in passing through.	Quantity of Water met with.	Organic Remains.	Remarks.

The entry under each of these heads should be full and clear, so that it may be easily intelligible

to everyone who has occasion to refer to it. The descriptions of the strata should be made in the manner suggested on a foregoing page.

Rate of Progress and Cost of Boring.—There are probably no engineering operations in which the rate of progress is so variable as it is in that of boring. That such must necessarily be the case will be obvious when we bear in mind that the strata composing the earth's crust consist of very different materials; that these materials are mingled in very different proportions, and that they have in different parts been subjected to the action of very different agencies operating with very different degrees of intensity. Hence it arises not only that some kinds of rocks require a much longer time to bore through than others, but also that the length of time may vary in rocks of the same character, and that the character may change within a short horizontal distance. Thus it is utterly impossible to predicate concerning the length of time which a boring in an unknown district may occupy, and only a rough approximation can be arrived at in the case of localities whose geological constitution has been generally determined. Such an approximation may, however, be attained to, and it is useful in estimating the probable cost; and to attain the same end, for unknown localities, an average may be taken of the time required in districts of a similar geological character. The following, which are given for this purpose, are the averages of a great number of borings executed under various conditions by the ordinary methods. The progress indicated represents that made in one day of eleven hours.

			ft.	in.
1. Tertiary and Cretaceous Strata	To a depth of 100 yards.	Average progress,	1	8
2. Cretaceous Strata, without flints	" " 250 "	" "	2	1
3. Cretaceous Strata, with flints	" " 250 "	" "	1	4
4. New Red Sandstone	" " 250 "	" "	1	10
5. New Red Sandstone	" " 500 "	" "	1	5
6. Permian Strata	" " 250 "	" "	2	0
7. Coal Measures	" " 200 "	" "	2	3
8. Coal Measures	" " 400 "	" "	1	8
General Average	" " 275 "	" "	1	9

When the cost of materials and labour is known, that of the boring may be approximately estimated from the above averages. Should hard limestone or igneous rock be met with, the rate of progress may be less than half the above general average. Below 100 yards, not only does the rate of progress rapidly increase, but the material required diminishes in like proportion, so that for superficial borings, such as are frequently undertaken for the discovery of hematite iron ore, no surface erections are needed, and the cost sinks to two or three shillings a yard.

Arrangements with Contractors.—Borings are usually executed by contract; but the terms of the contract are very variable. As the work is of such an uncertain character, no contract could be made that would render the contractor liable to unlimited loss in the event of unforeseen difficulties occurring. Hence the condition is always accepted that the cost of such difficulties shall, with certain limitations, be borne by the parties for whom the boring is to be made. The difficulties included in this saving clause are: meeting with hard limestone, igneous rock, or quicksand, and any great and unusual obstacle arising from any cause. When such difficulties occur, the work proceeds as day labour, to be paid for weekly by the employer, at a rate previously agreed upon, till the difficulty

has been surmounted, when the terms of the contract again come into force. A clause in favour of the employer enables him to abandon the boring whenever the contract becomes so suspended.

The uncertainty of the work, even under these conditions, renders it necessary for the contractor to allow a wide margin for contingencies, and hence these terms of contract are the most expensive to the employer. Probably the cheapest arrangement that could be made would be to agree with the contractor to furnish the necessary materials, to provide the requisite labour, and to conduct the operations for a fixed sum per week, the employer paying the cost of carriage. Such an arrangement is not, however, an altogether equal one, inasmuch as no provision is made in favour of the employer for delays on the part of the contractor. The most equitable terms of contract seem to be the foregoing, with the addition of some such clauses as the following. That if the boring be completed before a given time, the contractor shall receive a premium of a certain sum per week for every week unexpired, which sum may be the amount paid for the last week's work, or a certain proportion of that amount. That if the boring be not finished within the time specified, the operations shall be carried on from that time, with the same men and appliances, at a reduction of 25 per cent. on the weekly cost previously agreed upon. And that should any delay or neglect on the part of the contractor be proved to the satisfaction of an arbitrator mutually accepted, the employer may, if he think fit, cause the contractor to abandon the work, and to remove the material at his own cost. On the continent of Europe such terms as these are frequently made.

When the contractor undertakes to execute the work for a fixed sum, exclusively of the special difficulties already described, he does not include in that sum the cost of conveying the materials to and from the spot, or that of erecting sheds, or making a road if one be required. These expenses are borne by the employer. The sum demanded by the contractor is calculated in the following manner. It is assumed, allowing a sufficient margin for contingencies, that the mean cost of the first 10 yards will be 3*s.* 6*d.* a yard; that of the second 10 yards, 7*s.* a yard; that of the third 10 yards, 10*s.* 6*d.* a yard, and so on in arithmetical progression, increasing by 3*s.* 6*d.* at each 10 yards. Thus by multiplying the mean cost a yard for the total depth, as determined in this way, by that depth, the total cost is readily found. The following formula will give this cost in pounds sterling, with the least possible labour of calculation:

$$S = 0 \cdot 5\, d\ (0 \cdot 175 + 0 \cdot 0175\, d)$$

S being the sum sought, and d the depth of the boring in yards.

Example.—Required the cost of a boring 200 yards deep.

$$\text{Here} \quad 100\{0 \cdot 175 + (0 \cdot 0175 \times 200)\} = £367 \cdot 5.$$

In some cases, the engineer will find it advantageous to purchase a set of boring tools and apparatus, and to execute the work himself rather than entrust it to a contractor. Under such an arrangement, he will purchase the material with the intention of selling it again when the borings are completed, the difference between the buying and the selling price being considerably less than the amount allowed by the contractor for contingencies, depreciation, and profit. It is hardly possible to give an exact estimate of the cost of the apparatus for a given depth until all the conditions of the case are known; moreover, the variations in the price of raw material must necessarily affect the cost in no inconsiderable degree. But an approximate mean value may be found which may serve as a basis of calculation. The following values are of this character, the

estimates being founded upon the assumption that the tools and appliances employed are such as we have previously described.

	£
1. Hand-boring apparatus for a depth of 6 or 7 yards .. .. about	4
2. Tools and other appliances for a depth of 15 yards, including shear-legs and one diameter of tools ..	12
3. Tools and other appliances, as in No. 2, but including two diameters of tools, and tubes	18
4. Tools and other appliances for a depth of 25 yards, including shear-legs complete, two diameters of tools, and tubes	40
5. Tools and other appliances for a depth of 50 yards, including shear-legs complete, three diameters of tools, and two diameters of tubes	90
6. Tools and other appliances for a depth of 100 yards, including shear-legs complete, three diameters of tools, and two diameters of tubes	240
7. Tools and appliances for a depth of 200 yards, including shear-legs complete, four diameters of tools, and three diameters of tubes	400
8. Tools and appliances for a depth of 300 yards, including boring frame complete, four diameters of tools, and three diameters of tubes	1000

The diameters of the tools in the foregoing sets are 3 inches; 4 inches and 3 inches; 5 inches, 4 inches, and 3 inches; and 6 inches, 5 inches, 4 inches, and 3 inches respectively.

Special Systems of Boring.—Improvements effected in the mechanical appliances used in boring have led to the introduction and establishment of special systems by which rapidity of execution is gained. Another advantage which these systems aim at securing is the possibility of extracting the rock in the form of a solid core without having recourse to extraordinary and slow means. The advantages accruing from rapidity of execution and the extraction of solid cores are very great, and hence the system which renders such advantages obtainable is of very great importance and value. As an offset against these merits, however, there exists in every case the defect of complexity of parts. The appliances required by the ordinary methods of boring are few and extremely simple. They are such as anyone may obtain for himself, and use without much special knowledge. But the systems in question involve complicated erections, the employment of steam power, and the attendance of trained and experienced workmen. Hence such a system can be applied only by a firm or a company who make it their special business to execute borings with it, and it therefore becomes necessary to contract with these if it be desired to obtain the advantages which the system offers. For this reason it seems undesirable to describe the details of such systems of boring with the minuteness observed in respect to the ordinary methods. The following descriptions will, therefore, deal only with their main and distinctive features.

The systems of the special character in question, which have proved their merits and come into common use, are two in number, and are known respectively as "Mather and Platt's system," and the "Diamond system." The former of these is less special in the character of its appliances than the latter, and demands, therefore, fuller description and illustration. The essential principle of Mather and Platt's system consists in the substitution of a flat hempen or wire rope for the iron rods employed in the ordinary methods. By this means a great saving of time is effected in raising and lowering the cutting tools, the operations being performed as rapidly as those of raising and lowering the sludger. The appliances introduced, and the methods of working adopted to render such a substitution possible, as well as other and minor advantages claimed for the system, will be best understood from the following description, given by Mr. Mather in a paper read before the Institution of Mechanical Engineers:

Mather and Platt's System of Boring.—"The distinctive peculiarities of this method of boring

consist in the means adopted for giving the percussive and rotary actions to the boring tool; and also in the construction of the tool or boring head, and of the shell pump for clearing out the hole after the action of the boring head. Instead of these implements being attached to rods, they are suspended by a flat hemp rope, about $\frac{1}{2}$ inch thick and $4\frac{1}{2}$ inches broad, such as is commonly used at collieries; and the boring tool and shell pump are raised and lowered in the bore-hole as quickly as the buckets and cages in a colliery shaft. The following is a description of the construction and the methods of working this machine: The flat rope A, Fig. 224, from which the boring head B is suspended, is wound upon a large drum C, which is driven by a steam-engine B, having a reversing motion, so that one man can regulate the operation with the greatest ease. This winding drum is 10 feet in diameter in the large machine, and is capable of holding 3000 feet length of rope $4\frac{1}{2}$ inches broad and $\frac{1}{2}$ inch thick. All the working parts are fitted into a wood and iron framing E, thus rendering the whole a compact and complete machine. On leaving the drum C the rope passes under a guide pulley F, and then over a large pulley G carried in a fork at the top of the piston-rod of a vertical single-acting steam cylinder H; this cylinder, by which the percussive action of the boring head is produced, is shown to a larger scale in the vertical sections, Figs. 226 and 227. In the larger size of machine here shown, the cylinder is fitted with a piston of 15 inches diameter, having a heavy cast-iron rod 7 inches square, which is made with a fork at the top carrying the flanged pulley G of about 3 feet diameter, and of sufficient breadth for the flat rope A to pass over it. The boring head having been lowered by the winding drum to the bottom of the bore-hole, the rope is fixed secure at that length by the clamp J; steam is then admitted underneath the piston in the cylinder H by the steam valve K, and the boring tool is lifted by the ascent of the piston-rod and pulley G; and on arriving at the top of the stroke the exhaust valve L is opened for the steam to escape, allowing the piston-rod and carrying pulley to fall freely with the boring tool, which falls with its full weight to the bottom of the bore-hole. The exhaust port being 6 inches above the bottom of the cylinder, while the steam port is situated at the bottom, there is always an elastic cushion of steam retained in the cylinder for the piston to fall upon, thus preventing the piston from striking the bottom of the cylinder. The steam and exhaust valves are worked with a self-acting motion by the tappets M M, which are actuated by the movement of the piston-rod; and a rapid succession of blows is thus given by the boring tool on the bottom of the bore-hole. As it is necessary that motion should be given to the piston before the valves can be acted upon, a small jet of steam N is allowed to be constantly blowing into the bottom of the cylinder; this causes the piston to move slowly at first, so as to take up the slack of the rope and allow it to receive the weight of the boring head gradually and without a jerk. An arm attached to the piston-rod then comes in contact with a tappet, which opens the steam valve K, and the piston rises quickly to the top of the stroke; another tappet worked by the same arm then shuts off the steam, at the same time the exhaust valve L is opened by a corresponding arrangement on the opposite side of the piston-rod. By shifting these tappets the length of stroke of the piston can be varied from 1 to 3 feet, according to the material to be bored through; the height of fall of the boring head at the bottom of the bore-hole being double the length of the piston stroke. The fall of the boring head and piston can also be regulated by a weighted valve on the exhaust pipe, checking the escape of the steam, so as to cause the descent to take place slowly or quickly as may be desired.

"The boring head B, Fig. 224, is shown to a larger scale in Figs. 228 to 231, and consists of a wrought-iron bar about 4 inches diameter and 8 feet long, to the bottom of which a cast-iron cylindrical

block *a* is secured. This block has numerous square holes through it, into which the chisels or cutters *b*, of which two different arrangements are shown, are inserted with tapered shanks, so as to be very firm when working, but at the same time easily taken out for repairing and sharpening. A little above the block *a* another cylindrical casting *c* is fixed upon the bar B, which acts simply as a guide to keep the bar perpendicular. Higher still is fixed a second guide *d*; but on the circumference of this are secured cast-iron plates made with ribs of a saw-tooth or ratchet shape, catching only in one direction. These ribs are placed at an inclination like segments of a screw-thread of very long pitch, so that, as they bear against the rough sides of the bore-hole when the bar is raised or lowered, they assist in turning it, causing the cutters to strike in a fresh place at each stroke. Each alternate plate has the projecting ribs inclined in the opposite direction, so that one half of the ribs are acting to turn the bar round in rising, and the other half to turn it in the same direction in falling. These projecting spiral ribs simply assist in turning the bar, and immediately above the upper guide *d* is the arrangement by which the definite rotation is secured. To effect this object two cast-iron collars, *e* and *f*, are cottered fast to the top of the bar B, and placed about 12 inches apart. The upper face of the lower collar *e* is formed with deep ratchet-teeth of about 2 inches pitch, and the under face of the top collar *f* is formed with similar ratchet-teeth, set exactly in line with those on the lower collar. Between these collars, and sliding freely on the neck of the boring bar B, is a deep bush *g*, which is also formed with corresponding ratchet-teeth on both its upper and lower faces; but the teeth on the upper face are set half a tooth in advance of those on the lower face, so that the perpendicular side of each tooth on the upper face of the bush is directly above the centre of the inclined side of a tooth on the lower face. To this bush is attached the wrought-iron bow *h*, by which the whole boring bar is suspended with a hook and shackle O, Fig. 224, from the end of the flat rope A. The rotary motion of the bar is obtained as follows: When the boring tool falls and strikes the bow, the lifting bush *g*, which during the lifting has been engaged with the ratchet-teeth of the top collar *f*, falls upon those of the bottom collar *e*, and thereby receives a twist backwards through the space of half a tooth; and on commencing to lift again, the bush rising up against the ratchet-teeth of the top collar *f* receives a further twist backwards through half a tooth. The flat rope is thus twisted backwards to the extent of one tooth of the ratchet, and during the lifting of the tool it untwists itself again, thereby rotating the boring tool forwards through that extent of twist between each successive blow of the tool. The amount of this rotation may be varied by making the ratchet-teeth of coarser or finer pitch. The motion is entirely self-acting, and the rotary movement of the boring tool is ensured with mechanical accuracy. This simple and most effective action taking place at every blow of the tool produces a constant change in the position of the cutters, thus increasing their effect in breaking the rock.

"The shell pump, for raising the material broken up by the boring head, is shown in Figs. 232 and 233, and consists of a cylindrical shell or barrel P of cast iron, about 8 feet long and a little smaller in diameter than the size of the bore-hole. At the bottom is a clack *a* opening upwards, somewhat similar to that in ordinary pumps; but its seating, instead of being fastened to the cylinder P, is in an annular frame *c*, which is held up against the bottom of the cylinder by a rod *d* passing up to a wrought-iron bridge *e* at the top, where it is secured by a cotter *f*. Inside the cylinder works a bucket *b* similar to that of a common lift-pump, having an indiarubber disc valve on the top side; and the rod *d* of the bottom clack passes freely through the bucket. The rod *g* of the bucket itself is formed like the long link in a chain, and by this link the pump is suspended from the shackle O, at

the end of the flat rope, the bridge *e* preventing the bucket from being drawn out of the cylinder. The bottom clack *a* is made with an indiarubber disc, which opens sufficiently to allow the water and small particles of stone to enter the cylinder; and in order to enable the pieces of broken rock to be brought up as large as possible, the entire clack is free to rise bodily about 6 inches from the annular frame *c*, thereby affording ample space for large pieces of rock to enter the cylinder when drawn in by the up stroke of the bucket.

"The general working of this boring machine is as follows: When the boring head B is hooked on the shackle O, at the end of the rope A, its weight pulls round the drum and winding engine, and by means of a brake it is lowered steadily to the bottom of the bore-hole; the rope is then secured at that length by screwing up tight the clamp J. The small steam jet N is next turned on, for starting the working of the percussion cylinder H; and the boring head is then kept continuously at work until it has broken up a sufficient quantity of material at the bottom of the bore-hole. The clamp J which grips the rope is made with a slide and screw I, whereby more rope can be gradually given out as the boring head penetrates deeper in the hole. In order to increase the lift of the boring head, or to compensate for the elastic stretching of the rope, which is found to amount to 1 inch in each 100 feet length, it is simply necessary to raise the top pair of tappets on the tappet rods whilst the percussive motion is in operation. When the boring head has been kept at work long enough, the steam is shut off from the percussion cylinder, the rope unclamped, the winding engine put in motion, and the boring head wound up to the surface, where it is then slung from an overhead suspension bar Q, by means of a hook mounted on a roller for running the boring head away to one side, clear of the bore-hole.

"The shell pump is next lowered down the bore-hole by the rope, and the débris pumped into it by lowering and raising the bucket about three times at the bottom of the hole, which is readily effected by means of the reversing motion of the winding engine. The pump is then brought up to the surface, and emptied by the following very simple arrangement: It is slung by a traversing hook from the overhead suspension bar Q, and is brought perpendicularly over a small table R in the waste tank T; and the table is raised by the screw S until it receives the weight of the pump. The cotter *f*, which holds up the clack seating *c* at the bottom of the pump, is then knocked out, and the table being lowered by the screw, the whole clack seating *c* descends with it, as shown in Fig. 233, and the contents of the pump are washed out by the rush of water contained in the pump cylinder. The table is then raised again by the screw, replacing the clack seating in its proper position, in which it is secured by driving the cotter *f* into the slot at the top, and the pump is again ready to be lowered down the bore-hole as before. It is generally necessary for the pump to be emptied and lowered three or four times in order to remove all the material that has been broken up by the boring head at one operation.

"The rapidity with which these operations may be carried on is found in the experience of the working of the machine to be as follows: The boring head is lowered at the rate of 500 feet a minute. The percussive motion gives twenty-four blows a minute. This rate of working continued for about ten minutes in red sandstone and similar strata is sufficient for enabling the cutters to penetrate about six inches in depth, when the boring head is wound up again at the rate of 300 feet a minute. The shell pump is lowered and raised at the same speeds, but only remains down about two minutes, and the emptying of the pump, when drawn up, occupies from two to three minutes.

"In the construction of this machine it will be seen that the great desideratum of all earth boring

has been well kept in view, namely, to bore holes of large diameter to great depths with rapidity and safety. The object is to keep either the boring head or the shell pump constantly at work at the bottom of the bore-hole, where the actual work has to be done; to lose as little time as possible in raising, lowering, and changing the tools; to expedite all the operations at the surface; and to economize manual labour in every particular. With this machine, one man standing on a platform at the side of the percussion cylinder performs all the operations of raising and lowering by the winding engine, changing the boring head and shell pump, regulating the percussive action, and clamping or unclamping the rope: all the handles for the various steam valves are close to his hand, and the brake for lowering is worked by his foot. Two labourers attend to changing the cutters and clearing the pump. Duplicate boring heads and pumps are slung to the overhead suspension bar Q ready for use, thus avoiding all delay when any change is requisite.

"Solid cores, showing perfectly the nature and quality of the rock, with its angle of inclination and other particulars, may be obtained by operating the boring head in the following manner: Having removed all the inside cutters, leaving only the outside circle of cutters and the few cross chisels alternating with them round the circumference of the block, by continued working a slightly conical core will be formed, which may be made longer or shorter according to the length and inclination of the cutters; this core becomes finally jammed fast between the cutters and broken off at the root, and is then brought up to the surface by the boring head. Beautiful specimens of coal have by this means been brought up, large enough to show the quality and dip of the seam."

The Diamond System of Boring.—The diamond system differs essentially in principle from every other method of rock boring. We have already shown that the percussive action invariably attributed to the common boring tools was rendered necessary by the difference of hardness between the cutting tool and the rock being in favour of the latter. The inventor of the diamond drill sought to reverse this condition by employing for the cutting tool the hardest known substance, namely, the diamond, and thereby to remove the necessity for the percussive action. The costly character of the material would, however, have precluded the practicability of the idea had it existed only in the form in which it is used as a gem. But fortunately it is found in comparative abundance in an imperfectly crystallized form known as "carbonate." This carbonate, which until recently had but little commercial value, is of a dull black colour, and is characterized by little or no cleavage. This latter quality is a very valuable one, as it removes the liability to split, to which the more perfect variety is exposed. But although the carbonate is much harder than the rock to be pierced, it could not be made to *cut* the latter by means of a cutting edge after the manner of steel instruments, and therefore another mode of applying it had to be discovered. It it is a well-known fact, that when two substances of unequal hardness are rubbed together, the softer is worn away by the friction; this action of abrasion was chosen as that through which the diamond could be made to act most effectively in piercing rock. Thus, in the diamond system of boring, the rock is worn down by abrasion; and though such a process may appear at first sight a slow one, experience has shown that when effected with suitable appliances, it is, on the contrary, far more rapid than the ordinary process of fracture by blows from a falling tool.

In applying the diamond to rock drilling, a number of the stones are set in the edge of a steel cylinder or crown to which the rods are attached. To fasten the stones in securely, holes are made in the metal just sufficiently large to receive them, and the metal is hammered over so as to bury them, leaving each stone only the amount of projection necessary to enable it to rest upon the rock, and to

allow the débris and water to pass beneath the crown. The setting of the stones needs to be done with care, for the greatest danger to the drill arises from the liability of the stones to come out. The wear of the stones even in hard rock is trifling; but the loosening of one of them, besides occasioning trouble and loss, is a source of danger to the others. As the stones are set in a ring, the minimum amount of work is performed; for the work of abrasion by the stones is required only to form an annular space, and not to remove the rock within the circumference of the bore-hole, as in other systems. When this annular space has been cut, the solid core may be extracted, and the advantage gained thereby is not merely an economy of labour, but the obtaining of clear and certain evidence concerning the character of the strata passed through. Indeed, the chief merit of the diamond system, great as that of expeditious execution may be, consists in its bringing out the core of the bore-hole solid instead of in the powdered state to which it is reduced by other systems.

The crown in which the diamonds are set is screwed on to the end of steel tubes, which serve as rods for transmitting the motion from the surface. These tubes or hollow rods terminate at their upper extremity in a universal clutch, which allows them to turn, and which is connected with a cross-head sliding between two vertical uprights. To keep the bore-hole truly vertical, these need to be very carefully set and fixed. A rotary motion is communicated to the rods from a steam-engine by means of suitable gearing. The speed of rotation is usually about 250 revolutions a minute. The weight upon the crown is made to vary, according to the hardness of the rock and the rate of progress required, from 400 lb. to 800 lb., which weight is furnished by the rods, increased by a weight, or diminished by a counterweight, according to the depth attained. During the progress of the boring, water is forced down the hollow rods to remove the débris from the annular space in which the diamonds are working, and to keep the latter cool. The core, when formed, passes into a core-tube, in which it is held, on the rods being withdrawn, by sliding wedges or clips. Suitable gearing of an ordinary character is provided for raising and lowering the rods; and for remedying accidents the common appliances are made use of.

The diamond drill will cut through the hardest rock; even emery having been pierced at the rate of 2 inches a minute. The ordinary rate of progress during actual boring is stated to be from 2 inches to 3 inches a minute in granite and the hardest limestones; 1 inch a minute in quartz; and 4 inches a minute in sandstone. These are the speeds attained in ordinary practice. In soft strata, such as clay and sand, the diamond cutter is of no use whatever. When these strata are met with, the ordinary tools are employed until hard rock is reached.

The following statement, showing results obtained in some of the bore-holes executed by the Diamond Rock-Boring Company, is due to Major Beaumont, R.E., chairman of the Company:

Locality.	Including the Time occupied in getting the Machinery on the Ground.		Actual Working Days.	Depth.
	Commenced.	Ended.		ft.
Girrick	October 1, 1872	November 30, 1872 ..	54	902
Moorsholme	June 1, 1872	July 27, 1872	48	641
Fishburne	November 9, 1872 ..	February 1, 1873 ..	54	434
Beeston	February 22, 1873 ..	July 22, 1873	146	1008
Chewton	December 31, 1873 ..	July 13, 1873	168	802
Loftus	March 16, 1873	June 7, 1873	60	[illegible]40
Ballymena	April 7, 1873	May 24, 1873	42	558

At present, the Diamond Rock-Boring Company, who own the patents for the invention, do not sell machines, nor allow them to be used on payment of a royalty. But they undertake to execute borings upon terms similar to those already described, though at higher rates. The cost of the transport of the material to and from the site of operations is borne by the employer when the depth does not exceed 500 feet; above that depth and below 1000 feet the employer pays only the cost of transport *to* the site of the boring; and above a depth of 1000 feet, the whole cost of transport is borne by the Company. The employer finds engine power and water, or pays the Company 25*l.* a month for providing the same. The engine required is an ordinary portable engine, with a cylinder of about 11 inches diameter. The cost of a covering for the machinery and of a shed for the protection of the workmen from the weather is also charged to the employer.

Upon the foregoing conditions, and the usual one relating to difficult strata, the Company undertake to bore up to 1500 feet in depth, at the following rates of charges, exclusive of the cost of lining, namely, 8*s.* a foot for the first hundred feet; 16*s.* a foot for the second hundred feet; 1*l.* 4*s.* a foot for the third hundred, and so on in arithmetical progression, increasing 8*s.* at each hundred feet. Above 1500 feet in depth, special rates are charged. Upon this basis, the cost of a bore-hole may be readily calculated by the following formula:

$$S = 0{\cdot}5\,d\,(0{\cdot}4 + 0{\cdot}004\,d).$$

S being the sum sought, and d the depth of the bore-hole in feet; the amount is given in pounds sterling.

Example.—Required the cost of a bore-hole 600 feet in depth.

$$\text{Here } 300\ \{0{\cdot}4 + (0{\cdot}004 \times 600)\} = 840l.$$

CHAPTER IV.

SHAFT-SINKING.

SECTION I.

TOOLS USED IN EXCAVATING ROCK.—The tools used in coal-mining are few in kind and simple in construction; but though their simplicity of form and generally well-known character are such as to lead writers on subjects of mining engineering frequently to omit them altogether from their descriptions, they nevertheless constitute a subject of no small importance, and one that is deserving of close attention. In the adapting of means to an end, the design and quality of tools should form a primary consideration. In mining especially, where the efficiency of the tools employed depends so much upon their being suitably designed for and applied to the work required of them, the subject claims careful attention. It is impossible to obtain the highest degree of productiveness in the labour of the miner without a full and accurate knowledge of the mineral composition and the structure of the rocks among which he works, and of the particular capabilities of the several means which he employs in attacking them. Also the character of mining operations is such as to occasion a rapid wear of the tools, and a consequent necessity for their frequent repair and renewal. In a mine employing several hundred men, these are matters involving a considerable cost, both of time and of money. Moreover, in countries and localities that are far removed from the centres of manufacture, it becomes necessary not only to repair, but to make all, or nearly all, the tools required in the mine; and in such a case a knowledge of the methods of manufacture, as well as of the principles upon which their construction and use are founded, becomes absolutely indispensable. A want of such knowledge has often occasioned the failure of important enterprises that might otherwise have proved eminently successful. We shall, therefore, describe somewhat in detail the tools and appliances used in excavating rock, and the labour of keeping them in a proper condition, before entering upon the subject of opening out a colliery.

Shovels.—The shovel is a well-known and very serviceable tool, the use of which is to collect and remove into corves, tubs, barrows, or carts, the rock that has been loosened by other means. It consists essentially of a "plate" for passing under and retaining the loosened material, and a wooden handle to which the plate is fixed. To give lightness and stiffness to the plate, and at the same time to enable it to pass readily beneath the rock and to retain its load, it has received several forms according to the use to which the tool is to be applied; and to allow it to be used in more or less confined spaces, the handle has been made of various lengths. The plate is always of iron, and the front edges are steeled. Stiffness and carrying capacity are obtained by making the plate slightly concave. The upper portion, or "shoulder" of the plate, is provided with "straps" or "ears" to receive the handle; and at the part where it joins the straps it is buckled upwards to

give strength. This part is called the "crease." The handle or helve is always of ashwood, and is circular in section. It terminates in a crutch-handle or hilt, a form which is preferred by miners to the common D or "eyed" handle. To lessen the necessary degree of stooping, the handle is set at an angle with the plate. The sizes of shovels are distinguished by the width of the plate, measured in its widest part; they vary from 10 inches for heavy work, to 16 inches for light work, such as shovelling coal or loose earth. The strain upon the shovel when in use is mainly thrown upon the crease and the top strap, and it is at this part that they yield by the parting of the strap. Strength in the strap and the crease is therefore a requirement in a shovel.

The form of shovel used for gravel is that shown in Fig. 234, Plate XXI. The plate is 10 inches wide, and the "mouth" or entering part is pointed so as to form two edges. This form renders it very suitable for entering closely compressed or heavy ground. The handle is 30 inches long, and is set at an angle of about 150° with the surface of the plate.

Fig. 235 represents a "frying-pan" filling shovel, as used in the north of England and in some other districts. The plate is nearly circular, with a short point, and the edges are turned up to give it concavity; the breadth is 14 inches, and the length 16 inches; the handle is 24 inches long, and is set at an angle of 142° with the plate. The weight of this tool is 7 lb. 14 oz.; it is very well adapted for loading coal into tubs, and it is very extensively employed at collieries.

Fig. 236 represents a "round-mouthed" filling shovel, which is very generally employed for shovelling loose stuff not too heavy. The plate is 16 inches wide, and 15 inches long; the handle is 23 inches in length, and is set at an angle of 147° with the plate. The weight of this tool is also 7 lb. 14 oz. Fig. 238 represents a sinking shovel, $11\frac{1}{2}$ in. × 14 in., the handle of which is 23 inches in length.

For use in clay ground, the "clay-spade," shown in Fig. 237, is used. The plate of the spade is long and narrow, and has a square mouth. Sometimes the plate is curved so as to form a portion of a cylinder, as shown in the figure. When of this form it is often called a "grafting spade." The clay-spade is used by forcing it into the ground with the foot placed upon the shoulder, and to form a convenient tread a piece of iron is riveted upon the shoulder. This tool is much used in soft or clay ground.

The shovel is the only tool which is never made at the mine: it is always purchased ready made, and when broken it is seldom capable of being repaired. The cost of gravel shovels, 10 in., 11 in., and 12 in. wide, is from 25*s.* to 35*s.* a dozen; all steel, from 60*s.* to 70*s.* Frying-pan and round-mouthed filling shovels cost, according to size, from 35*s.* to 48*s.* a dozen; all steel, round mouths, from 45*s.* to 60*s.*; and clay-spades, 12 in. × $6\frac{1}{2}$ in., about 35*s.* a dozen.

Picks.—The pick, maundril, or hack, as it is variously named, is the most important tool of the miner. Its use is to loosen masses of rock, or to chip away small fragments. It consists of an iron head formed of two arms, and a wooden handle or helve fitted into an eye in the middle of the head or stem. The arms are steeled at the tips, and are either pointed or chisel-edged, according to the work required of the tool. When pointed, the point is formed by a square taper. Such wedge-shaped extremities enable the arm to penetrate the joints of fissured rocks, or between the laminæ of shaly rocks. When the tip of one arm of the pick has been forced into the rock, it is used as a lever to fracture the mass by pressing or *prising* upon the helve. Thus the action of the pick combines that of the hammer, the wedge, and the crow-bar or lever. It acts as a hammer in delivering a blow; as a wedge, in penetrating and disrupting the rock; and as a lever, in forcing out large masses. These

several actions must be borne in mind when considering the form and construction of a pick. With the chisel edge it is very frequently used to chip off fragments of rock, as in dressing the sides of an excavation. In this case it combines the action of the chisel and the hammer.

In using the pick as a lever the strain is thrown on the helve in the eye, and the helve yields in that part by "wincing," that is, by a crushing of the fibres. To provide against this wincing, the bearing surface at each end of the eye should be made as long and as wide as possible. It is obvious that the sharper the edges of the feather, that is, the widened portion of the helve that fits into the eye, the greater will be the tendency to wince. Wedging the helve very tightly into the eye, so as to make it press against the cheeks, also lessens the liability of the fibres to yield. Many devices against wincing have been adopted; the most effective of which, however, consist in lengthening the eye in the direction of the helve, in flattening the edges of the feather, and in providing the helve at that part with an iron strap or ring.

The pick-head is usually made of wrought iron. It consists of a central part called the "eye," made to receive the helve, and two shanks or stems. The sides of the eye are spread out to form cheeks, against which the sides of the helve may be firmly wedged. Generally the shanks are square in section, and their side varies in dimension from $\frac{3}{4}$ inch in light picks, to $1\frac{1}{8}$ inch in heavy picks near the eye, diminishing gradually towards the point. Sometimes the section of the shank is $1\frac{1}{4}$ inch $\times$ 1 inch, or $1\frac{1}{8}$ inch $\times$ $\frac{7}{8}$ inch, the longer side being in the direction of the helve, to give greater strength for prising. Frequently, when the section is square, the edges are chamfered down, and in some cases the chamfering is carried so far that the section approaches the octagonal form. The ends of the shank are steeled, and brought, as before remarked, either to a point or a cutting edge. The weight of the head varies from 2 lb. to 7 lb., according to the nature of the work to which the tool is to be applied; the difference of weight being caused by the larger section and the greater length of the shanks required for certain purposes. The helve is of ashwood, and consists of two portions, the haft and the feather; the latter portion is inserted into the eye, and fixed by wedging. The length of the helve also varies according to the nature of the work to be performed, from 24 inches to 34 inches.

Pick-heads are made straight, curved, or anchored. Straight-headed picks assist the reach, and are more suitable for getting into corner work than the curved or the anchored forms. They are always preferred for long-reaching or overhand work. When curved, the head is said to "sweep," and such a form is preferred for underhand work, the sweep causing the tool to fall into its work better than it would do if the head were straight. The degree of curvature is always slight. Sometimes, instead of curving the shanks, they are made straight and converging to the eye. This form is described as the anchored, and is very common in the north of England.

The tips of the shanks are sharpened on an anvil, and tempered to the requisite degree of hardness. The form of the cutting edge will be determined by the nature of the work to be performed. For hard ground the four-sided pyramid point is generally the most suitable. The rate of taper in such a case will also be determined by the character of the work. A quick taper or "bluff" point is stronger than a slow taper or "slim" point; but if the point is very bluff it will not penetrate the rock readily. When the tool is required to work in a narrow slit, it is obvious that the point must be slim, even if the nature of the rock is such as to require a bluff point, since the pick-head cannot be turned sufficiently to enable the bluff point to catch the side of the cut; and such a circumstance would soon cause the sides to come together, or "cut out," as it is termed. As the bluffness of the

point under such conditions is mainly dependent upon the length of the head, the latter is usually shortened to increase the bluffness. This relation between the rate of taper of the point and the length of the head is evident, for the shorter the head, the more obliquely it may be turned in a narrow cut. The pyramid point is very generally used for holing the coal; that is, for cutting a narrow slit in the seam; but the conditions existing in this case seem rather to require a chisel edge. The operation of holing consists in *chipping*, and for such a use the point is not suitable. It is somewhat remarkable that this form of cutting edge should still be used by hewers. With the exception of this case, whenever the pick is to be used for chipping the rock the chisel edge is adopted. The chisel edge is also suitable for penetrating the joints of rocks, or between their laminæ, as before remarked, so as to disrupt them by acting as a wedge, or to dislodge them by acting as a lever.

Picks may be divided, according to the nature of the work to which they are applied, into three classes, and described as "stone picks," "holing picks," and "cutting picks." The first of these are used in rock only; and to render them suitable for such heavy work they are made very strong and heavy. Holing picks are used for undercutting the coal, and are used either in the coal or in the underclay. In using them they are swung horizontally. Cutting picks are swung vertically for downward cutting, and are used for cutting or shearing off the coal at the sides of the stall or face, so as to divide the seam on each side after it has been "holed," for the purpose of causing it to fall. To avoid wasting the coal these side cuts are made as narrow as possible. Cutting picks have a slim point, and are sometimes made slightly heavier than the holing picks. Various forms are given to picks by continental nations, but those which we have described, and which will be found illustrated on Plate XXI., are almost exclusively employed in Great Britain and America.

Fig. 239 represents a holing pick in common use in South Wales. The head is straight, and 18 inches in length from tip to tip. The helve is $33\frac{1}{2}$ inches long, and the weight of the whole tool, fitted as shown, is 3 lb. 8 oz. The points of this pick are somewhat bluff.

Fig. 240 is a cutting pick used with the former. The head is straight, as in the holing pick. The length, however, is somewhat less, being 17 inches instead of 18 inches, and the helve is only $20\frac{1}{2}$ inches in length. The weight of this tool complete is 2 lb. 14 oz. The shanks of the pick in this case taper directly from the centre to the points, which it will be observed are slim.

The stone picks used in the same districts have curved heads, and are of considerably larger dimensions. Fig. 241 represents a "bottom pick," that is, a pick used for cutting the floor or thill of the coal seam. The head is $21\frac{1}{4}$ inches in length, and the helve $30\frac{1}{2}$ inches. The weight of this tool is 7 lb. 3 oz. The shanks in this case are provided with a chisel head 1 inch wide, one edge being horizontal and the other vertical.

Fig. 242 represents a stone pick, the head of which is 24 inches in length, and the helve $30\frac{1}{2}$ inches. The shanks are octagonal in section, and terminate, one in a wedge point, and the other in a chisel edge. The weight of this tool is 9 lb. 5 oz.

Fig. 243 represents a holing pick as used in North Wales. The head is 18 inches in length, and the upper side has a strong curvature or sweep. The cheeks are V-shaped, and the shanks terminate in chisel edges. The length of the helve is 28 inches, and the weight of the whole tool 2 lb. 10 oz. The cutting pick used with this holing tool is of a similar form, but has less sweep. It is also slightly heavier, and has slim points.

Fig. 244 is a heading pick used in the same locality. The head is $16\frac{1}{4}$ inches in length, and has a top sweep only. The cheeks are V-shaped, and the shanks taper regularly from the eye. The

helve is $27\frac{1}{2}$ inches in length, and the weight of the tool is 3 lb. A somewhat heavier form of this pick is used for dead work, and is called a "driving" or "metal driving" pick. It has a head $17\frac{1}{4}$ inches in length, a helve $27\frac{1}{2}$ inches long, and weighs 3 lb. 10 oz.

Fig. 245 represents the form of coal picks common in the north of England. The head is $17\frac{3}{4}$ inches in length; the lower side is straight, but the upper side forms two inclined planes. In plan the head is a regular lozenge-shaped figure, diminishing gradually from the eye to the points. The cheeks are semicircular and very small. The length of the helve is 32 inches, and the weight of the tool is 4 lb. 5 oz.

Fig. 246 is similar to the preceding, except that the head is anchored, a form much in favour in the northern coal-fields. The shanks in this case meet at an angle of 155°. The length of the head is 18 inches, that of the helve 32 inches, and the weight of the whole is 4 lb. 5 oz.

Fig. 247 represents a stone pick of the same district. The head is slightly anchored, and is provided with tapered V-shaped cheek pieces. The angles are deeply chamfered or bevelled, so as to give an octagonal section. Sometimes, however, the section is square. The shanks terminate in four-sided pyramidal points. The length of the head is $19\frac{3}{4}$ inches, that of the helve 30 inches, and the total weight of the tool 7 lb. Frequently these stone picks are made stronger, the length of the head being increased to 23 inches, and the weight to 8 lb.

An improved form of pick is shown in Figs. 248 and 249. This pick, which is made of cast steel throughout, is manufactured by Burys and Co., of Sheffield, and is known as the "interchangeable" pick. The merits claimed for this pick are, that being of solid cast steel, it will never require to be re-steeled, and will last longer than the ordinary pick; that as the helve is very endurable, and capable of being readily affixed to and removed from the head, one helve is sufficient for a number of tools; and that being thus interchangeable, when the pick requires to be resharpened, the helve need not be sent with the head to the fire, where it is liable to become shrunken from exposure to the heat. By sending only the head, not only does the helve escape damage, but the labour of carrying it is saved, and as one helve is sufficient for several picks, the labour of carrying helves is, under all circumstances, greatly lessened. To strengthen the helve, as well as to facilitate its easy application to the eye of the head, the feather is reduced, and a ferrule or hoop is affixed, as shown in the figure. By this means the liability to wince is removed, or at least very materially diminished. The cost of these helves is 1*s.* 9*d.* each, and that of the picks, 9*d.* per lb. for the lighter, and 8*d.* per lb. for the heavier kinds.

The re-sharpening of picks forms a very large and important part of the smith's work at a colliery. Even when used in coal, the point or edge of a pick will not stand long; but an hour's work, or less, is often sufficient to blunt the edge of a stone pick. Hence it will be evident that in a colliery employing several hundred men the repair of picks must necessitate a considerable amount of labour. It has been already remarked that picks are sharpened on the anvil. When much blunted, as stone picks frequently are, the tips will have to be drawn out a little by the striker's sledge. Heavy blows should in all cases be avoided, as they are liable to injure the quality of the steel, and the heat should not be allowed to exceed cherry redness. Care should also be taken to employ coal of a suitable quality. The tempering requires particular attention, and the smith will do well to regulate the degree of hardness by the character of the blunted edge. For example, if the edge be battered, a little higher degree of hardening may be desirable; if fractured, it may be well to temper to a lower degree. As we shall consider the subject of hardening and tempering when

treating of borers or drills, to avoid repetition we shall merely remark, with respect to picks, that the tips are tempered in the same manner by retaining the heat behind the tip, and quenching at a straw, or a very light blue colour.

A smith can, with the assistance of a boy, sharpen from eighty to one hundred tips an hour of coal picks, which are usually only slightly blunted when sent to the smithy. Some smiths will get through a larger number than this, but one hundred an hour is very good work. In the case of stone picks, however, the points and edges of which are usually sent up much battered, a smaller number of tips will be sharpened in the hour. It should be considered satisfactory work if a smith, with the assistance of a striker, can draw out, sharpen, and temper fifty tips in that time.

The spare time of the smith is usually occupied in making picks. There are two methods of making picks, which we shall briefly describe, and as an illustration we will assume that the tool is to be of medium size. A length of about 14 inches is first cut off an inch bar of iron square in section. The middle of this piece is then heated and "upset" by striking it on the ends until a "swell" is formed in that part about $1\frac{1}{8}$ inch diameter. Next a cut is made through the middle of the swell by means of a "clift," as shown in Fig. 250, and a "drift" of the required form and shape driven in to form the eye. The sides of the eye are subsequently hammered out to form cheeks of any desired shape. The next process is to steel the tips. This is effected by splitting the ends of the bar, inserting a tongue of steel, as shown in Fig. 251, and welding the whole together. Plenty of sand should be used in this operation to preserve the quality of the steel. It is a good plan to heat the iron to a welding heat, and then to insert the steel tongue, heated only to a cherry redness. Hard striking of the steel, as before remarked, should also be avoided. When the welding is complete, the shanks are reheated and drawn out to the required taper, and the sweep is given to the head if such be desired. It then only remains to sharpen and temper the tips.

Instead of forging the pick from a single bar of square section, a common practice is to take two flat bars, half the thickness of the single bar, and to curve them slightly in the middle to form the eye. The two bars are then welded together from the eye to the tips, a tongue of steel, as in the former case, being welded in between the ends, as shown in Fig. 252. To strengthen the eye, and to form a good bearing surface for the helve, a piece of iron may be welded in at each end of the eye. When this method of making picks is adopted, it is essential to make perfect welds, as otherwise the parts are liable to separate when in use.

A smith, with the assistance of a striker, will make about twelve pick-heads of medium weight in a day. Of the lighter kinds, he will make about fifteen; and of the heavier stone picks, only ten. Picks may be bought in England ready made at a price that is about equal to the cost of making them. But as they are made when the smith has nothing else to do, there will always be a gain in making them at the mine.

When the shanks of a pick have become worn down too short to be of any further use, it is a common practice to "line" them. The process of lining consists in cutting off the old tips, and welding on new pieces of iron, which are steeled in the same manner as the original tips. The labour of cutting, welding, steeling, and drawing down to the requisite taper is nearly as great as that of making a new pick. But an advantage lies in having an eye that has been proved capable of standing well. A smith and a striker will line from fourteen to sixteen picks a day, according to their weight.

The material employed in making picks should be of good quality. The nature of the work to

which a pick is applied is such as to subject it to severe strains; and to enable it to withstand these strains it should be made of the toughest iron. The steel used in the tips should also be of the best quality. If inferior steel be sent into a mine, its speedy return in a battered and fractured state will show that a saving of cost in that direction is not conducive to economy. Picks of cast steel throughout have lately been introduced; the only objection to their use is, their brittleness.

Wedges.—The wedge constitutes an important instrument in the hands of the miner. Large numbers of them are employed in every colliery, as many as a dozen being sometimes required by one miner. They are used to break down large masses of hard coal, to force out blocks of rock by driving them into the joints, and to dislodge masses of rock that have been loosened by blasting. In jointed or vughy rock they often do great service. Wedges are made of iron, and are steeled at the edge. In length they vary from 6 inches to 18 inches; but a common size is 12 inches. Their thickness is generally about 1 inch, and their breadth $1\frac{3}{4}$ inch. These dimensions, however, are frequently varied slightly.

Fig. 253 represents a coal wedge used in South Wales. The penetrating side forms a slender rectangular pyramid; the striking side is of an irregular eight-sided section, tapered from the base of the wedge. In side elevation the breadth diminishes uniformly from the striking face to the point. The length is $13\frac{1}{4}$ inches; in central section the breadth $1\frac{7}{8}$ inch, and the thickness $\frac{7}{8}$ inch. On the striking face the breadth is $1\frac{1}{8}$ inch, and the thickness 1 inch. The weight of this wedge is 3 lb. 14 oz.

Fig. 254 is a coal wedge used in North Wales. The tapering sides of this wedge are bounded by curved lines, instead of straight ones, as in the preceding example. The length is $11\frac{1}{2}$ inches, and in the greatest section the breadth is $1\frac{3}{4}$ inch and the thickness $\frac{7}{8}$ inch. The weight of this wedge is 3 lb. 9 oz.

Fig. 255 represents a wedge used in the north of England. The sides are straight, like those of South Wales. The length is 12 inches, and the greatest section, or base of the wedge, 6 inches distant from the point; is a rectangle, $2\frac{1}{4}$ inches broad by $\frac{7}{8}$ inch thick. The striking face is an irregular octagon, 1 inch broad by $\frac{3}{4}$ inch thick. The point is cut off to a rectangle $\frac{1}{8}$ inch in the side. The weight of the wedge is 4 lb.

Fig. 256 is a stone wedge, from the same locality. The length is $6\frac{1}{2}$ inches; the wedge end is $3\frac{1}{2}$ inches long, and is drawn in from a rectangular section $1\frac{1}{2}$ inch wide and $1\frac{1}{8}$ inch thick. The opposite end is drawn in by a tapering eight-sided section to a striking face $\frac{7}{8}$ inch in diameter. The weight of this wedge is 2 lb. 1 oz.

Sledges and Hammers.—Sledges and hammers are important tools in the hands of the miner. The distinction between a sledge and a hammer is founded on dimensions only; the hammer being intended for use in *one* hand, is made comparatively light, and is furnished with a short handle; while the sledge being intended for use in *both* hands, is furnished with a much longer handle, and is made heavier. Sledges are used for striking the drill in boring blasting holes, for driving wedges in rock and in coal, and for breaking up large masses of the latter. The blasting sledge and the wedge-driving sledge being employed under different conditions, require different forms and dimensions. The striking face of the blasting sledge should be flat, to enable the striker to deliver a direct blow with certainty upon the head of the drill; and to facilitate the directing of the blow, as well as to increase its effect, the mass of metal composing the head should be concentrated within a short length.

To cause the sledge to fly off from the head of the drill in the case of a false blow being struck, and thereby to prevent it from striking the hand of the man who holds the drill, the edges of the striking face are chamfered or bevelled down till the diameter is reduced by nearly one-half. This requirement is, however, but seldom provided for. When used for wedge driving, the head of the sledge is very frequently required to follow the wedge into the cleft, and to enable it to do this, the head must be made long and of small diameter; that is, the mass of metal composing the head must be distributed throughout a greater length. The striking face should be rather convex than flat, to avoid a sharp edge, which would soon be battered off by coming in contact with the edges of the rocks in the cleft. A longer handle or helve is also needed for the wedge-driving than for the blasting sledge.

The head of a sledge is of iron; it consists of a pierced central portion called the eye, and two shanks or "stumps," the steeled ends of which form the striking faces or "panes." The form of the head varies in different localities, but whatever the variation may be, the form may be classed under one of four types or "patterns." A very common form is that shown in Fig. 257, and known as the "Bully" pattern. By varying the width, as shown in Fig. 258, we obtain the "broad bully," the former being called for the sake of distinction the "narrow" bully. Another common form is the "Pointing" pattern, represented in Fig. 259. The form shown in Fig. 260 is designated as the "Bloat" pattern; and that given in Fig. 261 the "Plug" pattern. Each of these forms possesses peculiar merits which render it more suitable for certain uses than the others. The same forms are used for hammers. The eye is generally made oval in shape, but sometimes, especially with the bloat pattern, it is made circular, as shown in Fig. 260. The weight of a sledge head may vary from 5 lb. to 10 lb., but a common and convenient weight is 7 lb. The length of the helve varies from 20 inches to 30 inches; a common length is 24 inches for blasting, and 28 inches for wedge-driving sledges. The average weight of hammer heads is about 3 lb., and the average length of the helve 10 inches.

All the forms of sledge heads may be used for wedge-driving purposes, but that which is generally employed, especially for coal wedging, is the pointing pattern. The modification made in the form illustrated is merely in the length of the head. A common length of a coal-wedging sledge is 12 inches, with a diameter of about $2\frac{1}{4}$ inches in the thickest part. The stumps are tapered down to about $1\frac{1}{4}$ inch at the panes, and the angles of the stumps are taken off by a chamfer beginning near the eye and gradually increasing to form an octagonal section at the panes.

Fig. 262 represents a blasting sledge used in South Wales. The stumps are octagonal in section, and spring from a square block in the centre. The panes or striking faces, however, are circular and flat. The length of the head is $8\frac{3}{4}$ inches, that of the helve 27 inches, and the weight of the tool complete 7 lb.

Fig. 263 shows a coal sledge from the same district. The stumps in this, as in the preceding case, are octagonal in section, and are reduced by a uniform taper from a square central section. The panes are octagonal and slightly conical. The length of the head is 11 inches, that of the helve 28 inches, and the weight of the tool complete 8 lb. This sledge is also used as a stone sledge.

Fig. 264 represents a blasting sledge used in North Wales. The central block is an irregular octagon in section, formed by slightly chamfering the angles of a square section, and the stumps are chamfered down to form a regular octagon at the panes, which are flat. The length of the head is $7\frac{3}{4}$ inches, that of the helve 22 inches, and the weight of the tool complete 6 lb. 7 oz.

The coal sledge used in this district is similar in form to that used in South Wales. The length of the head is $11\frac{1}{2}$ inches, that of the helve 27 inches, and the total weight of the tool 7 lb.

The sledges used in the north of England have shorter heads, and are lighter than the foregoing. Fig. 265 represents one of these blasting sledges. The head is nearly square in section at the centre, and the panes are flat. The length of the head is 5 inches, that of the helve $24\frac{1}{2}$ inches, and the weight of the sledge complete 4 lb. 14 oz.

Fig. 266 is a coal sledge from the same district. The length of the head is 10 inches, that of the helve 30 inches, and the total weight $6\frac{1}{4}$ lb.

Sledges and hammers are usually made at the mine. The mode of manufacture may be briefly described as follows. Supposing it to be required to make a bully-head sledge of the ordinary weight, a length of about 12 inches is cut off a 2-inch bar of iron of square section. The angles of one end are then chamfered down, the chamfering being begun at one quarter of the length and continued to form an irregular, or, if desired, a regular octagon at the end, as shown in Fig. 267. The eye is then punched, and a drift of the requisite form and size is worked in, and left to keep the eye in shape during the operations of forging. The other end of the bar is treated in the same way, and the bar then divided in the middle by a clift. The angles of the newly formed ends having been chamfered down in the same way as the others, it only remains to steel the striking faces. This operation is effected in the following manner: A flat bar of steel, about two inches wide and half an inch thick, is heated to dull redness, and a piece of the bar equal in length to the width is nearly cut off by a clift, as shown in Fig. 268. The object of leaving the piece slightly attached is to enable it to be handled conveniently. The four corners of the piece are then hammered down to give it the form and dimensions of the sledge pane. This may be easily effected by bending the nearly severed piece first on one side, and hammering down two of the corners, and then bending it back on the opposite side, and hammering down the other two. This piece is then again heated to a cherry redness, and one stump of the sledge having been heated to a welding heat and placed with that end uppermost upon the anvil, the steel pane is laid upon it. A few blows upon the steel weld it firmly to the iron. The steel may then be broken from the bar by a few twists of the latter. When the other end has been steeled in the same manner, and the chamfered angles properly dressed down, the faces are hardened by heating them both to dull redness, and plunging the head into cold water.

Sledges made in the manner described will stand their work well, and when worn out, they may be easily resteeled. A smith, with the assistance of a striker, will make about seven 7 lb. sledges in a day, and resteel twelve. Ready-made sledges can be bought at a price equal to about the cost of making. But, like the picks, they occupy the smith's spare time. Ready-made iron sledges, however, seldom stand so long as the home-made ones. Instead of the iron sledges, solid cast-steel heads are very frequently employed in England. These are very durable. They cost from 9*d*. to 1*s*. per lb., according to size.

Pick and Sledge Handles or Helves.—The supply of pick and sledge handles, "helves," "shafts," or "sticks," as they are variously termed in different districts, constitutes a feature of some importance in the economy of a mine. The cost does not indeed form a large item in the accounts, but a prompt supply conduces to a full utilization of the time of the miner by preventing delay. Moreover, though handles may be purchased as cheaply as they can be made, there are times when the carpenters of a mine are unemployed, and the utilization of this leisure in making handles then

becomes a source of economy. The duration of a pick helve, of course, varies greatly with the quality of the wood and the character of the work to which it is subjected. Assuming a uniformity of quality in the material—for none but the most suitable should be employed—the life of a helve will depend mainly upon the hardness of the rock to be excavated. Thus a pick helve will last longer in soft coal than in hard coal, in hard coal than in moderately hard rock, and in moderately hard rock than in very hard rock. The extremes of duration may be taken as one month and twelve months; the latter is, however, seldom reached, and the mean will have to be taken much nearer the lower than the higher limit. Probably three months may be taken as a fair average. Thus every hundred hewers will require 400 helves a year, or about three dozen a month. In the hard coal seams of South Wales, the average life of a holing-pick helve is found to be only six weeks; in such a case, the supply required is about six dozen a month for every hundred hewers. In the hands of a stone miner, that is, one who works in rock as distinguished from coal, a pick helve will rarely last longer than a month. Thus every dozen of such men will require a dozen helves a month.

The qualities requisite in the material of a helve are, toughness combined with a moderate degree of hardness, elasticity, and lightness. The only wood readily procurable in this country which possesses these qualities in a sufficient degree is ash, and this wood should alone be employed. Besides the qualities of the material, the other requirements of a helve are, that its dimensions shall be such that it may be completely grasped by the hand, and held without cramping the fingers, a consequence of the diameter being too small, and that its section shall be such as will facilitate the use of the tool. To fulfil the latter condition, the handle of a shovel which has to be frequently turned in the hand is made circular in section; and the handle of the pick, which has to be held firmly in one position, and truly directed to a given point, is made oval. For similar reasons, the same section is given to sledge and axe handles. The shovel handle is made to terminate in a crutch or eye, both to afford a large and convenient pressing surface to one hand, and to give control over the plate so as to turn it, or prevent it from turning, as occasion requires. Shovel handles are rarely made at the colliery: they are furnished with the tool, and when broken the tool is generally rendered useless.

To make pick and sledge helves, a piece of ash of straight grain is selected, and cut up in the round into the length of the helves required. The diameter of the logs should be a little more than twice, or a little more than four times, the widest part of the feather, that is, the widened portion of the helve which fits into the eye. The cost of such logs varies in different localities, but generally they may be purchased in the rough state for 1*s.* 4*d.* or 1*s.* 6*d.* a cubic foot. When larger logs are used, some judgment is required to avoid waste of material. As wood increases in porosity from the centre of the tree outwards, the outer portion shrinks more in drying than the inner, and this circumstance, unless provided against, would cause the helves to warp. To remedy this tendency to warp, which, if not counteracted, would render the helve utterly useless, the log is so divided that the major or long axis of the ellipse formed by the cross section of the helve shall radiate from the centre of the log. To effect this, the log is first cleaved into halves, and then quartered by means of iron wedges, after which each quarter is cleaved in the most advantageous manner, as shown in Figs. 269 and 270. The portions nearest the centre make the best helves. When there is much difference in the size of the logs, or when helves of different sizes are required—for it is not always practicable to obtain timber of the exact size desired—the logs may be cleaved into unequal portions; and if the cleaver possess skill, there will never be much waste. A log 7 inches in diameter will cleave into nine

pick helves, and a log 13 inches in diameter will cleave into about three dozen pick helves, the width at the largest part of the feather being 3 inches, and the thickness from $1\frac{1}{8}$ inch to $1\frac{1}{4}$ inch. The necessity for the feather occasions a waste of material, a portion having to be cut away. As the feather is not required in sledge handles, the same log would furnish nearly twice as many of the latter as of the pick helves. It is well to cleave and rough-hew the helves while the timber is green, both because the operation is then more easily effected, and because any warping during the setting may be easily corrected in the dressing. The dressing, or shaping and smoothing, is performed by means of draw-knives and spokeshaves.

Two men can saw, cleave, and rough-hew about twelve dozen pick helves, Fig. 271, or nearly twice as many sledge helves, Fig. 272, a day. And of these rough-hewn helves, a man will dress about five dozen of pick, Fig. 273, or ten dozen of sledge helves, Fig. 274, in the same time. If only one man be employed after the logs are sawn, one and a half dozen of pick helves or three dozen of sledge helves may be considered a fair day's work.

The fitting of a helve requires some care. As it must be firmly fixed into the eye, it should be made to fit exactly. To ensure a perfect fit, it may be driven partly in and then withdrawn, when the too prominent parts will be indicated by the marks of the pressure to which they have been subjected. These parts having been reduced, the helve may be again inserted and driven into its place. But before wedging it in permanently, it will be necessary to ascertain that the stem is square with the helve. To do this the end of the helve should be placed against the toe of the left foot, to keep it in a fixed position, and an arc struck with the point upon the ground. The pick should then be turned, and with the helve in the same position against the foot, the other point should be applied to the ground, when, if it move in the same arc, the stem is shown to be properly set. The wedge used for fixing the helve should be of hard oak, and equal in breadth to the length of the eye. An entrance for the wedge is made in the middle of the feather by means of a chisel. Sledge and axe helves are set and fixed in a similar manner.

The proper fixing of helves is a matter of some importance, for, as we have already remarked, a perfect condition of the tools employed is greatly conducive to their efficiency, and hence to the productiveness of the labour of the miner. At many collieries the carpenter fits the helves to the picks, and for the helves so fitted the men pay from 5*d.* to 6*d.* each for picks, and 4*d.* each for sledges. The price of a pick helve, unfitted, is usually 4*d.* When bought by the dozen of helve makers, pick helves cost from 4*s.* 6*d.* to 5*s.* 6*d.* a dozen, according to length. Ordinary axe handles cost from 4*d.* to 6*d.* each when straight, and from 6*d.* to 8*d.* when bent.

Drills or Borers.—When the rock to be removed is too hard and tenacious to yield readily to the pick and wedge, recourse is had to the action of explosives. This mode of dislodging rock masses is described as "blasting." The operations of blasting consist in boring holes of suitable dimensions and in favourable positions in the rock, in inserting the charge of the explosive compound in the lower portion of the hole, in filling up with suitable material the remaining portion of the hole, and in exploding the charge. The principles upon which these several operations are conducted will be explained, and the details of their performance described, in a subsequent section. At present we have to deal only with the tools employed, and of these the drill or borer constitutes, for blasting purposes, the chief. The use of the drill is to bore the hole which is to receive the explosive charge. When describing the operations of prospective boring in search of coal, we called attention to the fact of rock being superior in hardness to steel, and to the consequent necessity of devising tools to

penetrate rock by fracturing it. In deep boring this end was attained by means of a sharp blow delivered through the medium of suitable tools, the chief of which was the chisel bit. The blow in this case was obtained by dropping the tool with the rods attached from a suitable height. In boring shallow holes for blasting purposes, the same conditions of hardness in rock and steel of course exist, and therefore the same modes of penetration, modified only to suit the altered circumstance of dimension, must necessarily be adopted. Thus, in rock drilling, as the operation of boring blasting holes is called, to distinguish it from deep or prospective boring, the chisel bit is employed, and in some cases the impact of the falling tool is relied upon to produce the necessary fracture or *chipping* of the rock. Such a tool is shown in Fig. 275, Plate XXII., and is called the "jumper." It consists of an iron or a steel rod, provided at each end with a chisel edge, and having a swell, technically known as the "bead," between the extremities, to give it greater weight. The bead divides the jumper into two unequal portions, each of which forms a chisel or cutting bit, with its shank or "stock." The shorter stock is used while the hole is shallow, and the longer one to continue it to a greater depth. The mode or using the jumper is to lift it by both hands to a height of about one foot, and then to let it drop, assisting it by a little force when necessary. After each blow the tool must be turned partially round, for reasons that have already been fully explained. Thus both in form and in action the jumper is similar to the chisel used in deep boring. But in rock drilling the conditions of position and direction are frequently changed. So long as the boring is vertically downwards, the jumper is a very effective tool; and in open quarries, where such borings are constantly needed, it is commonly employed. But in mining operations, drill-holes are more often required to be bored in some other direction, or, as it is termed, at an angle. The direction may be inclined downwards, horizontal, inclined upwards, or even, in some cases, vertically upwards. It is plainly obvious that in any one of these directions the jumper is utterly useless. To meet the requirements of these cases recourse is had to the hammer wherewith to deliver the blow, and the cutting tool or "drill" is constructed to be used with the hammer. To render the form of the jumper suitable for use in this way it is only necessary to cut out the bead, and to leave the ends flat for a striking face, and the form of the two chisels thus produced is that adopted for the ordinary rock drill.

It will be understood from the foregoing descriptions that a rock drill consists of the *bit* or chisel edge, the *stock*, and the *striking face*. Formerly drills were made of wrought iron, and steeled at each end to form the bit and the striking face. Now, however, it is usual to make them entirely of cast steel, which is sent to the mine in octagonal bars of the requisite diameter. The advantages of using steel stocks are numerous. The superior solidity of texture of steel renders it capable of transmitting the force of a blow more effectively than iron. Being stronger than the latter material, a smaller diameter of stock, and, consequently, a less weight are sufficient. This circumstance also tends to increase the effect of the blow by diminishing the mass through which it is transmitted, and to lessen the labour of transport. On the other hand, a steel stock is more likely to break than an iron one.

The cutting edge of a drill demands careful consideration. The remarks already made relatively to deep-boring tools apply equally to a drill, and therefore, to avoid repetition, the reader is referred to them. It may, however, be observed here, that though it will be necessary to adapt the angle of the edge to the hardness of the rock to be penetrated, that angle may be much less obtuse than in the case of deep boring, where the force of the blow is very great. To enable the tool to free itself well in the bore-hole, and to avoid introducing unnecessary weight into the stocks, the bit is made wider than the latter; this difference in width may reach as much as an inch. It is evident that in

hard rock the liability of the edge to fracture increases as the difference of width. The edge of the drill may be straight, as in the flat chisel for deep boring, or slightly curved. The straight edge cuts its way somewhat more freely than the curved, but it is weaker at the corners than the curved, a circumstance which renders it less suitable for very hard rock. It is also slightly more difficult to forge. Figs. 276, 277, and 278 show the straight and curved bits, and the angles of the cutting edges for use in rock. The width of the bit varies, according to the size of the hole required, from 1 inch to $2\frac{1}{2}$ inches.

The stock is octagonal in section, and is made in lengths varying from 20 inches to 42 inches. The shorter the stock, the more effectively does it transmit the blow, and therefore it is made as short as possible; for this reason several lengths are employed in boring a blast-hole, the shortest being used at the commencement of the hole, a longer one to continue the depth, and a still longer one, sometimes, to complete it. To ensure the longer drills working freely in the hole, the width of the bit should be very slightly reduced in each length. It has already been remarked that the diameter of the stock is less than the width of the bit; this difference may be greater in coal drills than in rock or "stone" drills; a common difference in the latter is $\frac{3}{8}$ of an inch for the smaller sizes, and from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch for the longer. The following proportions may be taken as the average adopted:

Width of the Bit.	Diameter of the Stock.	Width of the Bit.	Diameter of the Stock.
1 inch	$\frac{5}{8}$ inch	$1\frac{3}{4}$ inch	$1\frac{1}{8}$ inch
$1\frac{1}{8}$,,	$\frac{3}{4}$,,	2 inches	$1\frac{3}{8}$,,
$1\frac{1}{4}$,,	$\frac{7}{8}$,,	$2\frac{1}{4}$,,	$1\frac{1}{2}$,,
$1\frac{1}{2}$,,	1 ,,	$2\frac{1}{2}$,,	$1\frac{5}{8}$,,

The striking face of the drill should be flat. The diameter of the face is less than that of the stock in all but the smallest sizes, the difference being made by drawing in the striking end. The amount of reduction is greater for the larger diameters; that of the striking face being rarely more than $\frac{7}{8}$ of an inch.

The making and resharpening of rock drills constitute an extremely important part of the labour of the colliery smith. The frequent use of the drill and its rapid wear necessitate a daily amount of work of no trifling proportions, and the judgment and skill required in proper tempering render a high degree of intelligence in the workman indispensable; indeed, so much depends upon the smith whose duty it is to repair the miners' tools, that no pains should be spared to obtain a man capable of fulfilling that duty in the most efficient manner possible. Tools sent into the mine in an unfit condition are a source of delay as well as of irritation to the miners; and it must always be borne in mind, that the best tools may be spoiled in the smithy. The engineer or manager will do well to frequently direct his attention to this important adjunct to a colliery; and besides insisting on the work being carefully and properly performed, he should take care that coals and steel of suitable quality be supplied; for with bad materials it is impossible for the smith to turn out good work. Coals unfit for forge purposes will greatly injure the steel or the iron exposed to their influence, and inferior metal can never be wrought into good tools.

When the borer steel bars are supplied to the smith, he cuts them up as required into the desired lengths. To form the bit, the end of the bar is heated and flattened out by hammering to a width a little greater than the diameter of the hole to be bored. The cutting edge is then hammered up with

a light hammer to the requisite angle, and the corners beaten in to give the exact diameter of the bore-hole intended. As the drills are made in sets, the longer stocks will have a bit slightly narrower than the shorter ones, for reasons already given. The edge is subsequently touched up with a file. In performing these operations heavy hammering should be avoided as well as high heats, and care should be taken in making the heat that the steel be well covered with coal, and far enough removed from the tuyere to be protected from the "raw" air. Overheated or "burned" steel is liable to fly, and drills so injured are useless until the burned portion has been cut away.

Both in making and in resharpening drills, great care is required to form the cutting edge evenly, and of the full form and dimensions. If the corners get hammered in, as shown in Fig. 279, they are said to be "nipped," and the tool will not free itself in cutting. When a depression of the straight or curved line forming the edge occurs, as shown in Figs. 280 and 281, the bit is said to be "backward;" and when one of the corners is too far back, it is spoken of as "odd-cornered." When either of these defects exists — and they are unfortunately common—not only does the bit work less effectively on the rock, but the force of the blow is thrown upon a portion only of the edge, which, being thereby overstrained, is liable to fracture.

The hardening and tempering of steel is a matter requiring careful study and observation. It is a well-known fact, that a sudden and great reduction of temperature causes a notable increase of hardness in the metal. The reason of this phenomenon is not understood, but it is certain that it is in some way dependent upon the presence of carbon. The degree of hardness imparted to steel by this means depends upon the amount of the reduction of the temperature, and the proportion of carbon present in the metal, highly carburetted steel being capable of hardening to a higher degree, under the same conditions, than steel containing less carbon. Thus for steel of the same quality, the longer the range of temperature, the higher is the degree of hardness. But here we encounter another condition which limits the degree of hardness practically attainable. The change which takes place among the molecules of the metal in consequence of the change of temperature causes internal strains, and thereby puts portions in a state of unequal tension. This state renders the strained parts liable to yield when an additional strain is thrown upon them while the tool is in use; in other words, the brittleness of the steel increases with its hardness. Here again the proportion of carbon present comes into play, and it must be borne in mind, that for equal degrees of hardness, the steel which contains the least carbon will be the most brittle. In hardening borer-steel, which has to combine as far as possible the qualities of hardness and toughness, this matter is one deserving careful attention. It is a remarkable fact, and one of considerable practical value, that when oil is employed as the cooling medium instead of water, the toughness of steel is enormously increased.

The tempering of steel, which is a phenomenon of a similar character to that of hardening, also claims careful consideration. When a bright surface of steel is subjected to heat, a series of colours is produced, which follow each other in a regular order as the temperature increases. This order is as follows: Pale yellow, straw yellow, golden yellow, brown, brown and purple mingled, purple, light blue, full clear blue, and dark blue. Experience has shown that some one of these colours is more suitable than the rest for certain kinds of tools and certain conditions of working. The selection of the proper colour constitutes a subject for the exercise of judgment and skill on the part of the smith. For rock drills and picks, straw colour is generally the most suitable when the work is in very hard rock, and light blue when the rock is only of moderate hardness.

The processes of hardening and tempering drills are as follows: When the edge of the bit has

been formed in the manner already described, from three to four inches of the end is heated to cherry redness, and dipped in cold water to a depth of about an inch to harden it. While in the water the bit should be moved slightly up and down, for were this neglected, the hardness would terminate abruptly, and the bit would be very liable to fracture along the line corresponding with the surface of the water. In cold weather the water should be slightly warmed by immersing a piece of hot iron in it before dipping the steel. When a sufficient degree of hardness has been attained, the remainder of the hot portion is immersed until the heat is reduced sufficiently for tempering. At this stage it is withdrawn, and the colours carefully watched for. The heat which is left in the stock will pass down to the edge of the bit, and as the temperature increases in that part, the colours will appear in regular succession upon the filed surface of the edge. When the proper hue appears, the whole drill is plunged into the water and left there till cold, when the tempering is complete. When the edge is much curved or "bowed," the colours will reach the corners sooner than the middle of the bit. This tendency must be checked by dipping the corners in the water, for otherwise the edge will not be of equal hardness throughout. As the colours can be best observed in the dark, it is a good plan to darken that portion of the smithy in which tempering is being carried on.

The degree of temper required depends upon the quality of the steel and the nature of the work to be performed. The larger the proportion of carbon present in the metal, the lower must be the temper. Also the state of the blunted edges, whether battered or fractured, will show what degree of hardness it is desirable to produce. From inattention to these matters good steel is not unfrequently condemned as unsuitable.

To form the striking face, the end of the stock is heated to a dull red, and drawn out by the hammer to form a conical head. The extremity is then flattened to form a face from $\frac{1}{2}$ inch to 1 inch in diameter. This head is then annealed to a degree that will combine considerable toughness with hardness. The constant blows to which the head is subjected tend to wear it down very rapidly. There is great difference in the lasting qualities of steel in this respect; some drills will wear away more quickly at the striking than at the bit end.

A smith will, with the assistance of a striker, sharpen and temper about thirty single-hand drills of medium size in an hour, or twenty double-hand drills of medium size in the same time. Of course, much will depend on the degree of bluntness in the cutting edge; but assuming the drills to be sent up only moderately blunted, the foregoing may be taken as a fair average of the work of two men.

The cost of octagonal cast-steel bars for rock drills is about 55*s.* a cwt. Ready-made cast-steel drills may be purchased at about 65*s.* a cwt. Cast-steel hammers may also be purchased at a cost of about 9*d.* a lb. Such hammers deal a more effective blow than those made of iron, steeled on the panes, which are commonly used. They are also far more durable.

It will be evident from the foregoing remarks, that to enable a drill to stand properly it must be made of good material, be skilfully tempered in the smithy, and provided with a cutting edge having an angle and a shape suited to the character of the rock in which it is used. To these conditions may be added another, namely, proper handling; for if the drill be carelessly turned in the hole so as to bring all the work upon a portion only of the cutting edge, or unskilfully struck by the sledge, fracture or blunting will speedily result. Improper handling often destroys the edge in the first five minutes of using.

Drills, as before remarked, are used in sets of different lengths. The sets may be intended for

use by one man or by two. In the former case, the sets are described as single-hand sets, and they contain a hammer for striking the drills; in the latter case, the sets are spoken of as double-handed, and they contain a sledge instead of a hammer for striking. It may appear at first sight that there is a waste of power in employing two men, or, as it is termed, the double set, for that two men cannot bore twice as fast as one. This rate of speed can, however, be attained, and it is due less to the greater effectiveness of the stroke than to the fact that two men can, by repeatedly changing places with each other, keep up almost without intermission a succession of blows for an indefinite length of time; whereas, with the single set, the man is continually obliged to cease for rest.

On Plate XXII. will be found three sets of blasting gear: a set of coal-blasting gear; a set of single-hand stone-blasting gear; and a set of double-hand stone-blasting gear. In the first set, the drill shown in Fig. 283 is 22 inches in length; the cutting edge is straight and $1\frac{1}{2}$ inch wide, and the weight is $2\frac{1}{2}$ lb. The other drill, Fig. 284, is 42 inches in length; it has a straight cutting edge $1\frac{7}{16}$ inch wide, and weighs 4 lb. 10 oz. The hammer used with this set, and shown in Fig. 282, weighs 2 lb. 14 oz.; the length of the head is $4\frac{1}{2}$ inches, and that of the handle $7\frac{3}{4}$ inches. In the second, or single-hand stone set, the shorter drill, Fig. 288, is 22 inches in length; the cutting edge is strongly curved and is $1\frac{1}{2}$ inch in width, and the weight is 3 lb. 10 oz. The longer drill, Fig. 289, is 36 inches in length; the width of the cutting edge, which is curved as in the shorter drill, is $1\frac{7}{16}$ inch, and the weight is 6 lb. 5 oz. The hammer used with this set, and represented in Fig. 287, weighs 3 lb. 6 oz.; the length of the head is 5 inches, and that of the handle 10 inches. In the third, or double-hand stone set, the first or shortest drill, Fig. 294, is 18 inches in length, $1\frac{3}{4}$ inch wide on the cutting edge, and weighs $4\frac{1}{4}$ lb. The second drill, Fig 295, is 27 inches in length, $1\frac{11}{16}$ wide on the cutting edge, and weighs 6 lb The third, or longest drill, Fig. 296, is 40 inches in length, $1\frac{5}{8}$ inch wide on the cutting edge, and weighs $9\frac{1}{4}$ lb. The cutting edges of all these drills are strongly curved, as in the preceding set. The sledge used with this set, and represented in Fig. 293, weighs about 5 lb.

Auxiliary Tools used in Boring.—Besides the drill and the hammer, other tools are needed in preparing the hole for the blasting charge. If the bore-hole is inclined downwards, the débris or bore-meal made by the drill remains at the bottom of the hole, where it is converted into mud or "sludge" by the water there present. This sludge, as in the case of deep boring, has to be removed as the work progresses, to keep the rock exposed to the action of the drill. The removal of the sludge is effected by a simple tool called a "scraper." It consists of a rod of iron from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. in diameter, and of sufficient length to reach the bottom of the bore-hole. One end of the rod is flattened out on the anvil and made circular in form, and then turned up at right angles to the stem. The disc thus formed must be less in diameter than the bore-hole, to allow it to pass readily down. When inserted in the hole, the scraper is turned round while it is being pressed to the bottom; on withdrawing the instrument the sludge is brought up upon the disc. This operation, two or three times repeated, is sufficient to clear the bore-hole. The other end of the scraper is sometimes made to terminate in a ring for convenience in handling, as shown in Fig. 285, Plate XXII. Instead of the ring, however, at one end, a disc may be made at each end, as shown in Fig. 290, the discs in this case being of different diameter, to render the scraper suitable for different size bore-holes. Sometimes the scraper is made to terminate in a spiral hook or "drag twist," as represented in Fig. 297. The use of the drag is to thoroughly cleanse the hole before inserting the charge. A wisp of hay is pushed down the hole, and the drag end of the scraper introduced after it, and turned round till it has

become firmly entangled. The withdrawal of the hay by the drag wipes the bore-hole clean. Instead of the twist drag, the "loop" drag is frequently employed. This consists of a loop or eye, through which a piece of rag or tow is passed. The rag or tow is used for the same purpose as the hay, namely, to thoroughly cleanse and dry the bore-hole previous to the introduction of the charge.

Very frequently the "swab-stick" is used instead of the scraper to clear out the bore-hole. This is simply a deal rod bruised at one end by blows with a hammer until the fibres separate to form a kind of stumpy brush or "swab." When this is pushed down the hole, the sludge passes up around and between the fibres, which are then spread out by being pressed against the bottom of the hole. On withdrawing the swab the sludge is brought out with it. This operation, two or three times repeated, is sufficient to clear the bore-hole.

When the charge has been placed in the bore-hole, and the fuse laid to it, the hole needs to be tamped, that is, the portion above the charge has to be filled up with some suitable substance. For this purpose, a rammer, stemmer, or tamping iron, as the instrument is variously called, is required. This instrument is illustrated in Fig. 286. It consists of a metal bar, the tamping end of which is grooved to receive the fuse lying against the side of the bore-hole. The other end is flat. to afford a pressing surface for the hand, or a striking face for the hammer when the latter is needed. To prevent the danger of accidental ignition from sparks caused by the friction of the metal against silicious substances, the employment of iron stemmers has been prohibited by law. They are usually made of copper, or phosphor-bronze, the latter substance being more resisting than the former.

Sometimes in wet ground it becomes necessary to shut back the water from the bore-hole before introducing the charge of gunpowder. This happens very frequently in shaft-sinking. The method employed in such cases is to force clay into the interstices through which the water enters. The instrument used for this purpose is the "claying-iron" or "bull," represented in Fig. 292. It consists of a round bar of iron, called the stock or shaft, a little smaller in diameter than the bore-hole, and a thicker portion, called the head or poll, terminating in a striking face. The lower end of the shaft is pointed, to enable it to penetrate the clay, and the head is pierced by a hole about an inch in diameter to receive a lever.

Clay in a plastic state having been put into the bore-hole, the bull is inserted and driven down by blows with the sledge. As the shaft forces its way down, the clay is driven into the joints and crevices of the rock on all sides. To withdraw the bull, a bar of iron is placed in the eye, and used as a lever to turn it round to loosen it; the rod is then taken by both hands, and the bull lifted out. To allow the bull to be withdrawn more readily, the shaft should be made with a slight taper, and kept perfectly smooth. As the bull is subjected to a good deal of heavy hammering on the head, the latter part should be made stout. This tool, which should be considered as an extra instrument rather than as an essential part of a blasting set, is a very serviceable one, and should always be at hand in wet ground when gunpowder is employed.

Another instrument of this auxiliary character is the beche, Fig. 300, used for extracting a broken drill. It consists of an iron rod of nearly the diameter of the bore-hole, and hollow at the lower end. The form of the aperture is slightly conical, so that the lower end may easily pass over the broken stock of the drill, and being pressed down with some force, may grasp the stock in the higher portion of the aperture with sufficient firmness to allow of the two being raised together. When only a portion of the bit remains in the hole, it may often be extracted by means of the drag-

twist end of the scraper, or the swab-stick may be driven down upon the broken portion, and the latter withdrawn with the swab.

Cartridges.—Cartridges are merely cases made to contain the charge of the explosive compound employed. It was formerly the custom, when blasting in wet situations, to enclose the gunpowder in a canvas bag, well greased to keep out the water. The end of the fuse was inserted into the mouth of this bag, which was then firmly tied with string and dropped into the bore-hole. This bag constituted a cartridge, but of unsuitable form and material. Now paper cartridges are made of a size and shape that will fit the bore-hole, and the fuse is inserted into these through a hole in the upper end left for that purpose. When intended for use in wet situations, the cartridge is covered with linen and overlaid with various compounds to render it waterproof. In such a case, the hole through which the fuse is introduced is countersunk, and the sunken portion is, after the introduction of the fuse, filled up with grease. Cartridges are made of various diameters to suit bore-holes of all sizes, and of various lengths, according to the weight of the charge required. The use of cartridges greatly lessens the risk of accidental explosion; and a recent Act of Parliament prohibits the employment of gunpowder in coal mines in any other form. The cost of the cases is fully compensated by the prevention of occasions for waste.

Fuse.—The means by which the charge of explosive matter placed in the bore-hole is fired constitutes a very important part of the set of appliances used in blasting. The conditions which any such means must fulfil are: (1) that it shall fire the charge with certainty; (2) that it shall allow the person whose duty it is to explode the charge to be at a safe distance away when the explosion takes place; (3) that it shall be practically suitable, and applicable to all situations; and (4) that it shall be obtainable at a low cost. To fulfil the second and most essential of these conditions, the means must be either slow in operation, or capable of being acted upon at a distance. The only known means possessing the latter quality is electricity. The application of electricity to this purpose is of recent date, and though rapidly extending, it is yet confined within narrow limits. The means in common use are thus those which are slow in operation, and which allow thereby sufficient time between their ignition and the explosion of the charge for a person to retire to a safe distance. These means consist generally of a train of gunpowder so placed that the ignition of the particles must necessarily be gradual and slow. Formerly, the mode of constructing this train was as follows: An iron rod of small diameter and terminating in a point, called a "pricker," was inserted into the charge and left in the bore-hole while the tamping was being rammed down. When this operation was completed, the pricker was withdrawn, leaving a hole through the tamping down to the charge. Into this hole a straw, rush, quill, or some other like hollow substance filled with gunpowder was inserted and pushed down to the charge. A piece of touch-paper was then attached to the upper end of this train, and lighted. When the train became ignited, the powder being confined in the straw, except at the upper end, burned slowly down and fired the charge, the time allowed by the touch-paper and the train together being sufficient to enable the man who applied the match to retire to a place of safety. This method of forming the train did not, however, satisfy all the conditions mentioned above. It was neither practically suitable, nor readily applicable to all situations. The use of the iron pricker was a source of danger. The friction of this instrument against silicious substances in the sides of the bore-hole or in the tamping frequently occasioned accidental explosions. This danger was, however, very greatly lessened by the employment of copper or phosphor-bronze instead of iron for the prickers. But the method was very defective in

other respects. With many kinds of tamping there was a difficulty in keeping the hole open after the pricker was withdrawn till the straw could be got down. When the holes were inclined upwards, besides this difficulty, another was occasioned by the liability of the powder constituting the train to run out on being ignited. And in wet situations, special provision had to be made to protect the trains. Moreover, the manufacture of these trains by the workmen was always a source of danger. Nor was the system satisfactory under the most favourable conditions, for the aperture through the tamping was so large relatively to the size of the bore-hole that the effective work of the explosive was materially reduced thereby.

All of the defects pertaining to the foregoing system were removed by the introduction of the fuse invented by Bickford, and known as Bickford's safety fuse. The merits of this fuse are indeed such as to render it the most perfect of the slow-action means that could be devised. The train of gunpowder is retained in this fuse, but the details of its arrangement are changed so as to fully satisfy all the conditions previously laid down as necessary. It consists of a flexible cord covered with waterproof materials, having a central core of fine gunpowder, surrounded by hempen yarns twisted up into a tube, and called the countering. The outer casing is made of different materials according to the circumstances under which it is intended to be used. A central touch thread passes through the core of gunpowder. This fuse, which in external appearance resembles a piece of plain cord, is very certain in its action: it may be used with equal facility in holes bored in any direction; it is capable of resisting considerable pressure without injury; it may be used without special means of protection in wet ground; and it may be transported from place to place without risk of damage.

The combustion of the train of powder in a fuse takes place gradually, and the rapidity of the process greatly depends upon the dimensions and nature of the envelope or covering. In consequence of the compression, the gases liberated by the combustion of the first grains of powder cannot extend themselves in a backward direction, and hence the grains below become ignited only in consequence of the conductability of the several elements of the fuse as their temperature is brought up to the requisite degree. In the safety fuse, the conditions of slow burning are well provided for, and certainty is ensured by the touch thread through the centre of the core. As the covering of the core is indestructible, and as, moreover, the combustion of the core leaves in the small space occupied by it a carbonaceous residue, there is no passage whatever left through the tamping by which the gases of the exploding charge may escape, as in the case of the straw trains. Hence results an economy of force. Another advantage offered by the safety fuse is, that it may be made to carry the fire into the centre of the bursting charge if it be desired to produce rapid combustion. This fuse can also be very conveniently used for firing charges of compounds other than gunpowder, by fixing a detonating charge at the end of it, and dropping the latter into the charge of the compound. This means is usually adopted in firing the nitro-glycerine compounds, the detonating charge in such cases being generally contained within a metallic cap.

In using this fuse, a sufficient length is cut off to reach from the charge to a distance of about an inch, or farther if necessary, beyond the mouth of the hole. One end is then untwisted to a height of about a quarter of an inch, and placed to that depth in the charge. The fuse being placed against the side of the bore-hole with the other end projecting beyond it, the tamping is put in, and the projecting end of the fuse slightly untwisted. The match may then be applied directly to this part. The rate of burning is about two feet a minute.

Safety fuse is sold in coils of 24 feet length. The price varies according to the quality, and the

degree of protection afforded to the train to render it suitable for use in difficult situations. The following are the most useful qualities and prices:

		Per Coil of 24 feet.
No. 2.	Common fuse, for use in dry ground	4*d.*
„ 3.	White fuse, for use in dry and close places	4*d.*
„ 4.	Red fuse, for use in very damp and close places	4½*d.*
„ 6.	Thread sump fuse, for use in wet ground	5*d.*
„ 8.	Tape sump fuse, for use in wet ground	6½*d.*
„ 10.	Treble-countered fuse, for use in very wet ground where it is liable to be subjected to rough treatment	7½*d.*
„ 12.	Small guttapercha fuse, for use in very wet ground, or in water	10*d.*
„ 22.	Treble-wove fuse, of superior quality, and suitable for almost every mining requirement	6*d.*

Fuses similar in character and in quality to the foregoing are manufactured by several firms, and sold at about the same prices.

Classification of Rocks for Purposes of Excavation.—From the time of the commencement of the shaft in a new winning, to the final closing of the mine when the last load of mineral has been drawn, the whole labour of the miner proper consists in cutting and removing rock. All other operations are subsidiary to this. Hence it will be obvious on reflection that a knowledge of the mineral composition, the structure and texture, and the distinctive characters of rocks, is essential to the miner to enable him to apply his strength and his skill to the best advantage. An intimate acquaintance with the nature of the materials upon which he has to work, as well as of the tools by means of which the various operations are performed, is absolutely necessary to the production of a superior workman. Undoubtedly he may, by observation and reflection, acquire such knowledge in the course of his daily practice. But, unfortunately, the miner, as a rule, neither observes nor reflects beyond what is necessary to enable him to imitate his companions. Not having been taught how to look or what to look for, he performs his work like a machine, without troubling himself about the whys and the wherefores, or endeavouring to conform his action to the peculiar conditions of the case in which he finds himself. Moreover, when the circumstances are favourable, the lessons of individual experience are long and costly, while the collective experience of whole generations of former workmen and students is ready at hand, and may be had for the seeking. The miner, therefore, who wishes to excel in his arduous but useful calling, will do well to acquaint himself with the recorded observations of others, and to study diligently the principles upon which the operations that he is continually performing are conducted. He should also observe carefully for himself the nature of the rocks upon which he is working, and consider attentively the forms of the tools employed, and the modes of using them which long experience has taught to be the best. He will find a sound reason for every peculiarity of form and of method, and will come to discern the relations existing between these and the character of the rock. The possession of such knowledge will give him at least the satisfaction of feeling that he is working in an intelligent manner. But if the observant and thoughtful miner be compared with his unthinking comrade, it will be seen that this knowledge leads to something more than mere sentiments. The labour of such a man is rendered thereby far more productive, and his influence over his fellow-workmen becomes more marked in proportion as his knowledge is superior to theirs. The fact must have been remarked by every mine manager, and there will be none who will not desire to see such eminently practical knowledge more common among his men. It is, perhaps, too much to hope that the ordinary coal miner will, for some time to come, exert himself to labour thus intelligently. But the progress which is observable in the

improvements in mechanical appliances every day brought under his notice must tend to bring about such a result ultimately. Till then it is the duty of those who are set over him to direct his operations even in those minute details to which reference has been made.

In the first chapter of this work the composition and mode of formation of rocks were treated of somewhat in detail, and it is very necessary that these subjects should be fully understood. It was therein shown that rocks are composed mainly of a few mineral constituents differing from each other widely in appearance, and especially in hardness. It was also shown from the manner in which the rocks were built up, how these constituents were compacted together, and in many instances cemented into a strongly coherent mass. From these facts it is evident that great variation must necessarily exist in the hardness and coherence of rock, and that the more or less perfect development of the system of joints during the process of consolidation and desiccation must influence in a high degree its resisting powers. Thus rock composed mainly of quartz, as some of the silicious sandstones, will require much more labour to cut than some compounds of lime, as chalk or gypsum. And a rock that is abundantly jointed may be excavated with much greater facility than one in which the joints are but sparsely developed. Also it is evident that a stratified rock will yield more readily than one of the igneous class, in which no lamination exists. Thus it will be evident that the classification of rocks according to their power of resistance to excavation, and the adaptation of tools and other means to the requirements of each class, constitute a matter of great importance in the economy of mining. The employment of unsuitable means, or of suitable means improperly applied, occasions a wasteful expenditure of force, time, and money. Unfortunately, however, no complete classification is possible, nor can exact instruction be given respecting the manner of applying the means of extraction. The hardness and coherence of rocks varies by insensible degrees, and is not wholly dependent on their mineral composition. Hence, a general classification only can be adopted. And as the conditions of hardness, coherence, lamination, jointing, and cleavage are constantly varying, the instruction to be given respecting the most effective application of tools must partake of the same general character. Such a classification and such instruction are, however, valuable, inasmuch as they indicate the points upon which attention should be directed; and the educated engineer will find that he has gained much when he has explained the one and imparted the other to the uneducated wielder of the pick. In insisting thus strongly upon the necessity of the working miner being thoroughly acquainted with the character of the rock in which he is occupied, we have, besides the productiveness of his labour, another care in mind, namely, the security of his life and limbs. It can hardly be doubted that the lamentably large number of deaths that are annually caused by falls of rock are in a very great measure due to ignorance in this respect.

For the purposes of excavation, rocks may be classified into (1) Loose Rock; (2) Soft Rock; (3) Tender Rock; (4) Compact Rock; and (5) Hard Rock. The first of these classes, or loose rock, includes uncompacted sand, vegetable earth, and disintegrated rock of any kind that has little or no coherence among its particles. Soft rock comprises plastic clay, loam, and marl. Tender rock includes all rocks of an indurated character that have but little coherence between their laminæ, as shale, or that are much broken up by joints. Compact rock includes rocks of a moderately fine texture that have been firmly compacted and cemented, as sandstones, and some limestones. And hard rock comprises the igneous rocks, the hardest limestones, and the conglomerates.

Loose and soft rocks may be easily cut by the shovel and spade, and these tools will, therefore, be chiefly employed in excavating them. The pick will be required as an auxiliary instrument to

loosen the rock in some cases. In excavating tender rock, the pick will constitute the chief tool, the shovel being used merely to clear away the dislodged rock. In applying this tool, it must be borne in mind that rocks of a shaly structure cleave readily along the planes of lamination, but are often very resisting in the direction of right angles to these planes. When the rock is jointed, there will always be one direction in which any given block will yield more readily than in another. By taking account of the planes of lamination, cleavage, and jointing, means will be perceived by which the block may be dislodged with the least expenditure of force. Also the most suitable form and angle of cutting edge and degree of temper may be determined by a consideration of the mineral composition and structure of the rock. These and other circumstances peculiar to the case to be dealt with will afford abundant opportunity for the exercise of the judgment. When tender rock of a jointed character occurs in the roof of underground workings, it is of the highest importance to note its features attentively. Hardness and strength are qualities by no means identical. A rock-bed composed of silicious materials strongly cemented together may be so fissured by jointing as to fall readily when undermined. To ascertain the strength of a rock roof, the miner strikes it with some iron instrument, as a hammer, sledge, or pick; a dull sound indicates the existence of joints; and a sharp sound, free from ring or echo, continuity and strength. In placing the prop timber, it is obviously necessary to consider the character of the jointing, in order to obtain a maximum degree of security with a minimum expenditure of material. The excavation of compact rock is effected by means of the pick, the wedge, and explosive compounds. In proportion as compact rock approaches in character tender rock on the one hand, and hard rock on the other, the use of the manual tools or of the explosives will predominate. It must be remarked, however, that the use of explosives is rapidly extending even to rocks of the tender class. The dislodgment of hard rock can be effected only by means of explosives. The pick and the wedge are required as auxiliary tools to complete the dislodgment of blocks which has been only partially effected by the action of the explosive. The effective placing of the blasting holes requires a full appreciation of the character of the rock relatively to its mineral composition, its structure, texture, and system of jointing. In rock drilling by machinery, the structure and texture are particularly important; for while the mineral composition of the rock will determine the proper temper of the drill and the angles of its cutting edges, the structure and texture will determine its most suitable form. A cellular or "vughy" rock, for example, may be best penetrated by a form of drill which would prove less effective in a rock of compact texture. These questions will be more fully discussed in a subsequent section.

Machine Rock-Drills.—It will be understood from the foregoing descriptions and statements that the use of explosive compounds constitutes a large and an important part of the work of the miner. The application of these substances necessitates a very great expenditure of labour in drilling holes by means of which a favourable position for the charge may be obtained, and involves the occupation of long periods of time. The labour thus applied is becoming day by day greater in amount, not only in consequence of the more extensive use of explosive compounds for purposes of rock excavation, but also by reason of the rapidly increasing demand for mineral produce. The desire to keep pace with the general material progress, and to meet the requirements of an increasing consumption by lessening the manual labour of drilling and shortening the time occupied by the operation, has led to numerous attempts being made to substitute machine power for hand-labour. There also existed a weighty reason of a different character for making this substitution, a reason which is becoming every day more important, namely, the growing inclination of the miner to toil

less arduously than formerly, and to shorten the hours of work. Such a disposition on the part of the mining population has produced its natural effect in an augmentation of wages, and a consequent and proportionate increase in the cost of the produce. The restriction placed upon the output, and the frequent strikes by means of which this disposition has been carried into effect, have also rendered hand-labour uncertain, and this fact furnished an additional reason for making dependence upon it less absolute. Had these potent influences not been at work, it may be doubted whether sufficient inducement would have existed to persevere in the attempt after the first disheartening failures consequent on want of experience. But the circumstances of the times were such as hardly to admit of defeat, and hence, as the lessons of experience were multiplied, success was gradually achieved. The improved machines, actuated by steam in some situations, and by compressed air in others, showed themselves, after long and severe trials under the actual conditions that obtain in practice, capable of performing the work for which they were designed. This success, which has been attained in spite of the opposition of much prejudice and ignorance, has at length brought them into an established position, as a common mechanical appliance for mining purposes, and their use thus adopted and securely founded must rapidly and widely extend. Hence the subject of machine rock-drills has become one of great and peculiar importance, and as such it claims a prominent place and particular consideration in a work devoted to the principles and the practice of mining engineering.

If the substitution of machine for hand drilling be considered only from an economical point of view, it will appear less a saving of *money* than a saving of *time*. The merit of the machine lies in its ability to concentrate the work of a number of men upon one point, or, which amounts to the same thing, to increase the amount of work executed in a given time by a given number of men. By bringing the power of a more potent motor in aid of the miner, more rapid progress in excavating is made; but the cost, in most cases, remains undiminished. No doubt as improvements are effected in the machinery, and as the rate of wages increases, a marked diminution of the cost will make itself conspicuous among the advantages derived from machine work. But at present the gain is, in the main, limited to rapidity of execution. This gain will, of course, in numerous instances—perhaps in all in a greater or a less degree—involve indirectly a gain of money; but it will be by means of the saving in time. The saving of time is, however, a highly important advantage. In the cases of the Mont Cenis, the St. Gothard, and the Hoosac tunnels, it rendered practicable that which would otherwise have been impracticable. And in the case of ordinary mining operations, the ability to sink a shaft or drive a level or heading rapidly may ensure the success of an undertaking, and save indirectly the expenditure of large sums of money. It would, indeed, seem to be almost impossible to overestimate the magnitude of the numerous advantages accruing from the increased rate of progress due to the substitution of machine power for hand-labour. Hence the importance of the question remains paramount, even if no direct economy result from the substitution.

In comparing the rate of progress made with the machine drill with that obtained by hand-labour, the advancement of the excavation must be considered rather than the time occupied in boring the blasting holes. When a machine is once set in motion, the speed with which the boring progresses very greatly exceeds that which is reached when, under the most favourable circumstances, the operation is performed by hand. But the placing of the machine in the desired position; the fixing of it at the necessary angle, and the attention demanded by its other requirements; its removal from one situation to another as it becomes necessary to bore each succeeding hole; its

withdrawal for the blast to take place, and the inconvenience arising from its more or less bulky presence—all these matters, which together often occupy more time than the actual boring, tend to greatly reduce the rate of progress due to the more rapid action of the tool. Also the chances of accident to the machine, its inevitable wear and tear, and the time consequently spent in effecting repairs, must be taken into account. Hence the only comparison that can be of any value whatever is that which is founded upon the rate of progress of the excavation during a period of time sufficiently long to include the contingency of breakage, and the necessity for repairs. The longer the time of observation, the more trustworthy, of course, the information gained will be; thus the average daily advance of a heading during a period of six months will constitute a surer basis of comparison than the average daily advance which has been ascertained for only half that length of time. A justification of these remarks may be found in the fact that competitive trials extending over a few hours at the most are not unfrequently made the foundation for wild statements concerning the superiority of machine drilling. As this superiority actually exists, nothing is to be gained by attempts to enforce it by arguments which, to the experienced man, are of an obviously fallacious character.

The conditions under which a rock drill is required to work are of an altogether exceptional character. To suppose that the qualities which recommend a machine in ordinary situations must be equally desirable in a drill is to misunderstand the exigencies of the case. Under ordinary circumstances, the situation is chosen and the extent of space determined to suit the requirements of the machine, and all other conditions are made conducive to its efficient action. In the case of a rock drill, on the contrary, the conditions are determined by other considerations, and they are generally unfavourable in character. The machine is required to work in confined and difficult situations, and in positions that do not tend to promote its perfect action. It has to be quickly brought into and fixed in the place where it is needed, and as quickly removed when it has done its work. It is necessarily subjected to sudden and severe strains, and to rough handling, and it is exposed for long periods of time to the influence of moisture. And last, but not least, it is entrusted to the direction and care of ignorant men. This latter circumstance exercises an obstructive influence of which the inexperienced in these matters have but little conception. Hence it is evident that however effectively a machine drill may operate on the rock, it will be unfit for the purpose intended if its construction be not such as will render it conformable to these conditions.

One consequence of the peculiar conditions to which a machine drill is subjected is the exclusion of steam as a motor. The confined character of the situations in which the work has to be executed, and the difficulty of providing an adequate ventilation, render it undesirable to raise the temperature of the atmosphere, or to vitiate it by the abstraction of oxygen. Thus it has become necessary to have recourse to compressed air, which, besides being free from the qualities objectionable in steam, possesses others that render its employment conducive to coolness and purity in the atmosphere into which it is discharged. The compression is effected at surface, or outside the heading, and conveyed through pipes of suitable dimensions and materials to the points at which it is required. The necessity which exists for employing special machines to compress the air constitutes the chief objection to the use of the latter, which objection is doubtless of a somewhat serious character.

Machine drills of the common form penetrate rock in the same way as the ordinary hand drills already described, namely, by means of a percussive action. The cutting tool is, in most cases, attached directly to the piston-rod, with which it consequently reciprocates. Thus the piston with

its rod is made to constitute a portion of the cutting tool, and the blow is then given by the direct action of the steam or air upon the tool. As no work is done upon the rock by the back stroke of the piston, the area of the forward side is reduced to the dimensions necessary only to lift the piston, and to overcome any slight resistance due to the friction of the tool in the bore-hole. The piston is made to admit steam or air into the cylinder, and to cut off the supply and to open the exhaust as required, by means of tappet valves, or other suitable devices; and provision is made to allow, within certain limits, a variation in the length of the stroke. During a portion of the stroke, means are brought into action to cause the piston to rotate to some extent, for purposes that have been already explained. To keep the cutting edge of the tool up to its work, the whole machine is moved forward as the rock is cut away. This forward or "feed" motion is usually given by hand; but in some cases it is communicated automatically. The machine is supported upon a stand or framing which varies in form according to the situation in which it is to be used. This support is in all cases constructed to allow of the feed motion taking place, and also of the cutting tool being directed at any angle.

In another class of machine drills the diamond cutters are employed. As the construction and application of these drills are, with the exception of certain modifications of detail to suit the altered circumstances, precisely the same as those of the large machine for prospective boring, which has been already described, the reader is referred to the section in which that description is given for information on those points.

The foregoing is a general description of the construction and mode of action of percussive rock-drills. The numerous varieties now in use differ from each other rather in details of construction than in principles of action, and the importance of the difference is, of course, dependent upon that of the details. Before proceeding to describe and to illustrate these varieties, there are certain conditions to be laid down which every rock drill must fulfil in order to render it in all respects sufficient for the exigencies of practice. These conditions, which have been determined by experience, are the following:

1. A machine rock-drill shall be simple in construction, and strong in every part.
2. It shall consist of few parts, and especially of few moving parts.
3. It shall be as light in weight as it can be made, consistent with the first condition.
4. It shall occupy but little space.
5. The striking part shall be of relatively great weight, and it shall strike the rock directly.
6. No part other than the piston shall be exposed to violent shocks.
7. The piston shall be capable of working with a variable length of stroke.
8. The sudden removal of the resistance shall not be liable to cause injury to any part.
9. The rotary motion of the drill shall take place automatically.
10. The feed, if automatic, shall be regulated by the advance of the piston at each stroke.
11. The machine shall be capable of working with a moderate degree of pressure.
12. It shall be capable of being readily taken to pieces.

The support for a rock drill constitutes an indispensable and a very important adjunct to the machine. Upon the suitability of its form, material, and construction, the efficiency of the machine will largely depend. The material and the construction may be made to differ, and the form to vary widely; but whatever they may be, it is necessary to the effectiveness of the support that in its design the following conditions be fulfilled:

1. A machine-drill support shall allow the machine to be readily adjusted to any angle.

2. It shall be adjustable to uneven ground, and capable of being easily and quickly fixed in any position.

3. It shall be simple in construction, and of sufficiently light weight to allow of its being easily portable.

The first of the conditions laid down respecting the design of machine drills will be acknowledged as self-evident, when the circumstances under which they have to work are borne in mind. The character of these circumstances has already been described. It is important that the necessary simplicity should extend to every part of the machine, and not be confined to the mechanism proper. In every case it must be assumed, as an inevitable condition, that the machine will be entrusted altogether to unskilled hands, and therefore its construction and action must be such as to require no special knowledge to understand or to direct. The use ot every part should be obviously apparent, and its position in the machine and its form should be such as to occasion no difficulty in removing and replacing it, or in repairing it when out of order. Small levers and all kinds of jointed gear are objectionable, by reason of the rapid motion communicated to them, and their consequent liability to fracture and speedy wear, which liability is largely increased by the splashing with gritty water and other inevitable occasions of dirt to which a machine is constantly subjected in a mine. For the same reasons, external gear is especially to be avoided. It is open to question whether the increased simplicity obtained by hand-feeding gear does not outweigh in advantages the comparative complexity due to an automatic feed. There is much to be said in favour of both arrangements, and experience has not yet decided which of the two possesses the superior merits. It is urged against automatic feeding, that it introduces unnecessary complexity, for that if the action were perfect it could not give better results than those obtained by careful hand feeding; and that a perfect automatic action cannot be obtained by reason of the continual variation in the character of the rock. Against hand feeding it is urged, that it requires the constant attention of the man in charge, a fact which necessitates the employment of a man for every machine when several are fixed upon the same support: that it is impossible, when every care is taken, to feed at the same rate as the piston advances, and that, consequently, there must necessarily be a loss of efficiency in the blow due to this cause: that therefore it becomes necessary to employ an experienced and skilful attendant; and that, as a matter of fact, even with such an attendant, the work is often carelessly performed; the inevitable consequences of such negligence being in all cases a diminution of the efficiency of the machine, and in numerous cases a jamming or fracture of the tool. On the other hand, it is urged in favour of hand feeding, that there must always be a man in attendance upon a machine, and that he may as well be employed in actuating the feed-gear as in watching the action of the machine. That the system possesses the great advantage of enabling the attendant to vary the length of the stroke from less than an inch to several inches, according as light blows are needed to commence a hole, or full blows when the hole is fairly started. Also, this power of varying the force of the blow may be turned to useful account in sparing the cutting edge of the tool when excessively hard rock is met with, an advantage that tends to promote the regular progress of the work. On the part of the automatic feed, it is contended that the advantage of light blows when commencing the hole may be obtained by only partially opening the passage through which the steam or compressed air is admitted; and that it is possible, without introducing much complication of parts, to render the action of the feed perfect by making it dependent upon the advance of the piston at each stroke. These disputed points must, as before remarked, be decided by the results of experience.

The same circumstances which necessitate simplicity in a machine rock-drill also require strength in its several parts. It is evident that the rough work performed by a drill operating upon hard rock by percussive action, and the often rougher treatment to which the machine is subjected at the hands of those in charge of it, will speedily result in loose joints, and wear and fracture of the moving parts, unless each part possesses a degree of strength proportionate to the work required of it. In the endeavour to reduce the weight of the machine, this necessity is sometimes not borne sufficiently in mind.

The second condition, which requires a machine rock-drill to possess only few parts, and especially few moving parts, is to a great extent included in the first. Yet the parts themselves may be extremely simple in form, while, in consequence of their being multiplied, the machine possesses a considerable degree of complexity. The possession of numerous parts constitutes a serious defect, and when the multiplication of parts extends to those in motion, the defect assumes still graver proportions. As the larger portion of the wear and tear must come upon the moving parts of any machine, it is obvious that the greater the number of such parts, the more will the wear and tear be, and the greater the risk of breakage. Moreover, a large number of parts renders the design and the action of a machine difficult to be understood and directed by the persons in whose charge rock drills are usually placed, and to whose ignorance of mechanical principles we have already alluded.

The third condition, of light weight in a machine drill, is one the importance of which is generally acknowledged, but the bearing of which is not fully understood. In transporting the machine to the spot where it is required to work, in fixing it in the necessary position and at the desired angle, and in removing it when its work is completed, manual power has to be largely employed. Hence it is highly desirable that the weight of a machine should be such as to render it portable. In spacious headings for railway tunnels, where wheeled carriages running upon tramways may be used as the support, the necessity for portability in the drill hardly exists; but for all mining and quarrying purposes, that quality must be considered as an essential one. As before remarked, the necessity for reducing the weight in such case to the lowest practicable limit is generally acknowledged, and the efforts of inventors and manufacturers have been directed to effect this object. But in the prosecution of these attempts at improvement, the necessity of strength has not been kept always in view, and hence the first condition has been encroached upon. Light weight constitutes a very desirable quality in a machine drill for reasons already given; but for other reasons, strength is still more desirable. Lightness and fragility are related and inseparable; and it is certainly preferable to have a machine that can keep itself out of the repair shop, even if it necessitate a greater cost of labour to place it in position, than another of a more easily portable character that is subject to frequent derangement. Hence, in designing a rock drill, the necessity for strength and the necessity for light weight should be fully observed; but the exigencies of the case will require that the latter be made subordinate to the former.

The fourth condition is also one of considerable importance, especially when the machine is to be used in mining operations. In all underground workings, the free space is extremely limited, and everything which obstructs that space constitutes an impediment and a source of delay to the operations which are there being performed. The degree of obstruction, and consequently the importance of the hindrance, is dependent upon the extent of the space and the dimension of the obstructing body. When this space is a circular shaft, it is rarely more than 15 feet in diameter; and when a heading, its dimensions are usually much more restricted. Hence it is obvious that a

machine drill in such a situation must necessarily occupy a large proportion of the space in which the workmen are engaged, and that if this proportion be such as to greatly impede operations, the gain in rapidity of execution, due to the employment of the machine, will be nullified by delays in other directions. Thus the importance of compactness in the machine will on reflection be apparent. A due fulfilment of the condition of light weight will, to a great extent, satisfy that of compactness, since, other things being equal, the weight will depend upon the dimensions. Sometimes, in view of the great length of the space in a heading comparatively to its breadth, the dimensions of the machine have been accumulated in one direction, that is, it has been made of small diameter and of great length. This expedient is, however, objectionable on two grounds: first, because the great length renders the machine cumbrous to handle; and, second, because it prevents holes from being bored at any but slight angles. The latter consequence must be regarded as constituting a serious defect.

The fifth condition is one of great mechanical importance, and this importance does not appear to be generally recognized. In comparing the relative merits of rock drills, the number of strokes a minute which anyone is capable of making is often insisted upon as the basis of a comparison of efficiency, that one being considered the most efficient which is capable of making the greatest number of strokes. This notion is an altogether erroneous and a pernicious one, inasmuch as it tends to perpetuate and increase a somewhat serious defect. A high piston speed is undesirable in a rock drill mainly for two reasons. First, the resistance to be overcome is great. The operation of boring consists, as we have already shown, in fracturing the rock by a succession of heavy blows, and it is evident that the heavier the blow, within the limits of the endurance of the tool, the greater will be the effect. To obtain a heavy blow there must be a large moving mass. But an augmentation of the mass is, other things being equal, incompatible with an increase of the velocity. Hence it becomes desirable, as far as the third condition will allow, to renounce velocity in favour of mass; that is, as much as practicable of the weight of the machine should be concentrated in the piston and piston-rod. With such a disposition of the parts, the work of a drill must necessarily be more effective. Second, when the moving mass is light and the velocity high, not only is the great resultant vibration absorbent of force, but very destructive to the joints and conducive to fracture in the moving parts. And, moreover, the inevitable wear and tear are thereby immensely increased: so that the tendency to derangement is greatly augmented by the adoption of high velocities.

That part of the condition which requires the striking mass to impinge directly upon the rock is also worthy of careful attention, since the efficiency of the machine depends upon it in no inconsiderable degree. As several machines have been constructed in which this principle has been violated, it becomes desirable to determine clearly what the effect of interposing a body between the striking part and the rock is. Let M denote the mass of the striking part, M′ that of the body interposed, that is of the tool struck, V the velocity of the striking mass, and V_1 the common velocity of the two bodies after impact. Then we have

$$MV = (M' + M)\,V_1\text{; whence } V_1 = \frac{M}{M' + M}\,V.$$

Hence the effect of the blow will be proportional to

$$(M' + M)\,V_1^2 = \frac{M}{M' + M} \times MV^2.$$

The work developed by the motor is $\frac{1}{2}MV^2$, and thus it is evident that the effective work done upon the rock will be proportional to the fraction $\frac{M}{M' + M}$; that is, it increases as M increases, or as M′ diminishes. To take an example: Suppose a machine the piston and piston-rod of which weigh 24 lb., to which a tool is fixed weighing 8 lb., the velocity of the piston being 5 feet a second. In this case $M = \frac{32}{32 \cdot 2}$, $M' = 0$, and $V = 5$, and the work developed will consequently be $\frac{1}{2}\left(\frac{32 \times 5^2}{32 \cdot 2}\right) = 12 \cdot 4$ units of work. Suppose now the tool to be detached, and the piston to strike the head of the tool. In such a case $M = \frac{24}{32 \cdot 2}$, $M' = \frac{8}{32 \cdot 2}$, and $V = 5$, as before. The work done upon the rock will be

$$\frac{1}{2}\left(\frac{24 \times 5^2}{32 \cdot 2} \times \frac{\frac{24}{32 \cdot 2}}{\frac{8 + 24}{32 \cdot 2}}\right) = 7 \text{ units of work.}$$

Suppose, again, the weight of the tool to be added to the piston in order to have the same striking mass as in the first case. Then $M = \frac{32}{32 \cdot 2}$, $M' = \frac{8}{32 \cdot 2}$, and $V = 5$; and the work done upon the rock will be

$$\frac{1}{2}\left(\frac{32 \times 5^2}{32 \cdot 2} \times \frac{\frac{32}{32 \cdot 2}}{\frac{8 + 32}{32 \cdot 2}}\right) = 10 \text{ units.}$$

Thus the loss of efficiency due to the interposition of the tool, or, in other words, its separation from the piston, is about $16\frac{1}{2}$ per cent.

The sixth condition, which provides that no part of the machine shall be subjected to violent shocks, is one that is common to all kinds of machines. But in a rock drill there is greater difficulty in complying with the condition than there is in the case of machinery of an ordinary character. The impossibility which exists of connecting the piston with the means of admitting the motive fluid in an invariable manner is naturally the source of an irregularity in the action that is conducive to the occurrence of sudden and violent strains in various parts. In this respect, a rock drill is somewhat similar to a steam hammer; but the higher speed at which the former is driven, and the different conditions under which it has to work, intensify the effects in a very considerable degree. Hence it becomes necessary to direct special attention to the design and construction of those parts which are necessarily subjected to some degree of shock, or upon which a sudden and violent strain may be thrown. In the majority of cases, the valve gear is actuated by means of tappets, which are struck by the piston as it travels in the cylinder. It is evident that in such a case the whole of the parts which compose the valve gear are constantly subjected to shocks the violence of which increases with the speed of the piston. This must tend to cause a rapid wear and tear of these parts, which are necessarily of feeble dimensions. And as a matter of fact, these are the parts of a drill that are continually subject to derangement. What is needed, therefore, is a design and form of construction which shall reduce the inevitable shock to its lowest possible degree of intensity. A source of

accidental shock of an extremely violent and destructive character lies in the necessity for a variable piston stroke. The provision for this variation of stroke allows the piston, under certain circumstances, to come into contact with the cylinder cover. When, as is sometimes the case, the valve gear acts independently of the piston, the liability to this accident is greatly increased, and becomes a very serious defect. In the design and construction of every machine drill, this tendency of the piston to exceed the proper limits of its stroke should be constantly borne in mind, and means should be employed both to check that tendency and to lessen its effects.

A rock drill operates upon the rock, as we have seen, by striking a blow, and it is essential to the success of the operation that the blow should be struck with the full force of the stroke. When the rock is very hard, several blows may be struck in succession without either penetrating the rock or breaking away any part of it. A subsequent blow acting on the parts weakened by those already received, causes fracture, and the fractured portion instantly becoming detached, the hole is suddenly deepened. The piston will therefore have to advance farther at the next following stroke. Moreover, rocks vary suddenly and greatly in hardness, and often contain cavities, besides which they are always more or less traversed by joints. If all these circumstances are borne in mind, a little reflection will suffice to show that, even assuming perfect feeding to be possible, a rock drill could not operate with an invariable piston stroke, and that the piston must, in the matter of length of stroke, accommodate itself to the requirements of the moment. But as no automatic feed motion could be devised sufficiently accurate in its action to satisfy the demands of practice, and as hand feeding is by its nature more imperfect still, the necessity becomes obvious, not merely for a possible variation in the length of the stroke, but for a variation between somewhat wide limits. This condition renders it impossible to connect the piston in an invariable manner with the valve gear. Hence recourse has been had to tappet movements to actuate the valve, and in some instances the valve motion has been made wholly independent of the piston.

The eighth condition, which requires that the sudden removal of the resistance shall not be liable to cause injury to any part, is really comprised within the sixth, which lays it down that no part, other than the piston, shall be subjected to violent shocks. But it has been placed out in a separate form to give special prominence to a source of accidents to which machine rock-drills are especially exposed. As previously pointed out, rocks frequently contain vughs or cavities, and these cavities are not uncommonly of considerable dimensions. When a bore-hole enters one of these cavities, the resistance to the tool is suddenly removed. The removal of the resistance causes the piston to give its extreme length of stroke, and, in consequence of a tendency to exceed the limit, it often strikes against the cylinder cover. The destructive character of this accident has been already alluded to. A provision against its occurrence consists in allowing ample clearance space at the lower end of the cylinder.

The necessity for an automatic rotary motion in the drill or borer-bit is sometimes questioned, and recently a machine has been introduced in which this condition has not been complied with. But it ought to be evident on reflection that the non-fulfilment of the condition must occasion grave inconveniences. Besides the reciprocating motion communicated by the piston, the borer has two other motions, one of rotation, and one of progression. These motions must be both automatic, both communicated by hand; or one must be automatic, and one communicated by hand. In the first of these cases, of course, the condition will be fulfilled; in the second, it will not; and in the third, it may not be. If both motions are to be communicated by hand, it is evident that, to perform the operation

satisfactorily, two men will be needed to work the machine, for the attention required to give the progressive or feed motion is such as to preclude the practicability of one man attending to the other motion at the same time. This necessity would constitute a very grave objection to the use of a machine drill. If one motion is to be automatic and the other to be communicated by hand, it ought to be equally evident that self-regulation should be applied preferably to that motion which is the more simple in character, or which has to take place under the more simple conditions. When, therefore, we take into account the conditions under which the forward or feed motion must take place, which conditions have been already described, it will be obviously apparent that the automatic action should be given to the mechanism of rotation, and the more delicate motion of progression reserved for hand guidance.

The tenth condition, which requires an automatic feed to be regulated solely by the advance of the piston at each stroke, is one of essential importance. Indeed, it may fairly be stated that without an observance of this condition an automatic feed is practically impossible. It is true that mechanical contrivances that are not founded upon such a principle have been adopted, and are still in use; but their action is so unsatisfactory that it may reasonably be doubted whether a feed motion so produced is not inferior to that which may be communicated by hand; and when the superior simplicity of the latter is borne in mind, it will be plainly evident that such imperfect devices must sooner or later be abandoned. It has been shown by what means and in what manner the edge of the tool penetrates the rock, and a little consideration of those means and that manner will show also that any mechanism by which a regular progressive motion is communicated to the tool must necessarily be unsatisfactory in its action. With such a motion, no account is taken of the irregular manner of producing fracture in the rock, of variations in hardness, of the occurrence of joints and cavities, or of the comparative sharpness or bluntness of the cutting edge of the tool. A certain velocity of progression having been assumed, the inevitable consequence is, either that the tool is not kept properly up to its work, or it is pressed forward too rapidly. In both cases the result is a serious loss of effective work, often accompanied with no less serious delays. With these facts in view, the practical mind will at once comprehend the importance of observing this condition in the design of means for producing an automatic feed motion for a rock drill.

The eleventh condition, which requires that the machine shall be capable of working with a moderate degree of pressure, is one that must tend greatly to promote the successful employment of rock drills actuated by compressed air. The notable loss of work occasioned by a high degree of compression of air by means of steam, the heat generated by the process, the increased difficulty of storing and conveying the air, and the intense cold produced by its expansion when exhausted from the machine, all these consequences of high compression, with others of a less important character, tend to render the employment of high pressures objectionable; and, as a matter of fact, they are being abandoned. The use of a pressure exceeding four atmospheres is now rare; three atmospheres and under are the common pressures, and it may be predicted that the machine drill which will be generally adopted for mining operations will be capable of working effectively with a pressure of two atmospheres.

With respect to the twelfth condition, requiring a machine drill to be capable of being readily taken to pieces, little need be said. It will be sufficiently obvious from what has been stated already, that under the most favourable circumstances rapid wear and tear must necessarily occur, and that fracture and derangement are not altogether preventable. Hence it becomes necessary so to construct

the machine that it may be readily taken to pieces, and as readily reconstructed, by men who possess little knowledge of the nature of machinery.

A machine rock-drill may satisfy all the foregoing conditions, and yet by reason of the defective character of the support to which it is attached, it may be unsuitable to the work required of it. Hence it becomes desirable to carefully study the design and construction of a drill support, and to consider the requirements which it is needful to fulfil. Assuming the necessity for a high degree of strength and rigidity in the support, a primary condition is that it shall allow the machine to be readily adjusted to any angle, so that the holes may be bored in the direction and with the inclination required. When this requirement is not fulfilled, the machine is placed, in this respect, at a great disadvantage with hand-labour. If a machine drill is not capable of boring in any position and in any direction, hand-labour will have to be employed in conjunction with it, and such incompleteness in the work of a machine constitutes a serious objection to its adoption.

Besides allowing of the desired adjustment of the machine, the support must be itself adjustable to uneven ground. The bottom of a shaft which is being sunk, or the sides, roof, and floor of a heading which is being driven, present great irregularities of surface, and as the support must of necessity, in most cases, be fixed to these, it is obvious that its design and construction must be such as will allow of its ready adjustment to these irregularities. The means by which the adjustment is effected should be few and simple, for simplicity of parts is important in the support as well as in the machine, and for the same reasons. A large proportion of the time during which a machine drill is in use is occupied in shifting it from one position or one situation to another. This time reduces in a proportionate degree the superiority of machine over hand labour in respect of rapidity of execution, and it is therefore evidently desirable that it should be shortened as far as possible. Hence the necessity for the employment of means of adjustment which shall be few in number, rapid in action, and of easy management.

For reasons similar to the foregoing, the drill support must be of small dimensions, and sufficiently light to allow of its being easily portable. The limited space in which rock drills are used renders this condition, as we have shown in the case of the machine itself, an important one. It must be borne in mind that after every blast, the dislodged rock has to be removed, and rapidity of execution requires that the operations of removal should be carried on without hindrance. A drill support that occupies a large proportion of the free space in a shaft or a heading is thus a cause of inconvenience and a source of serious delay. Moreover, as it has to be continually removed from one situation to another, it should be of sufficiently light weight to allow of its being lifted and carried without difficulty. In underground workings, manual power is generally the only power available, and therefore it is desirable that both the machine and its support should be of such weight that each may be lifted by one man. Of course, when any endeavour is made to reduce the weight of the support, the necessity for great strength and rigidity must be kept in view.

In spacious headings, such as are driven in railway tunnel work, supports of a special kind may be used. In these situations the conditions of work are different from those which exist in mines. The space is less limited, the heading is commenced at surface, and the floor laid with a tramway and sidings. In such a case the support may consist of a massive structure mounted upon wheels to run upon the rails. This support will carry several machines, and to remove it out of the way when occasion requires, it will be run back on to a siding. But for ordinary mining purposes, such a support

is unsuitable. That which is now commonly used, and which appears best to satisfy the requirements, consists simply of a stretcher bar, which is fixed against the sides of a shaft or heading, or against the roof and floor of the latter, by merely lengthening it when in position. The machine is fixed to this bar by means of a clamp, which, when loosened, allows it to be directed at the desired angle. Another kind of support, often furnished with a drill, consists of a tripod, the legs of which are capable of being increased in length, and extended laterally to meet the inequalities of the ground. This support, however, has not sufficient stability, and—if the case of open quarry work requiring vertical or nearly vertical holes in situations where the stretcher bar cannot be applied be excepted—ought, therefore, never to be used.

An account of the gradual development of rock-drilling machines from their origin in America, through all the successive stages, down to the latest degree of perfection, would be intensely interesting and highly instructive; but it would be beyond the scope of the present work. We shall, therefore, merely remark that the first really practical solution of the problem is due to M. Sommeiller, whose machine was employed in excavating the Mont Cenis tunnel, and proceed at once to describe, illustrate, and compare the various machine drills that are now in successful operation. It is necessary to premise, however, that for the purpose of comparison, the following machines are selected of a size to bore a hole $1\frac{1}{2}$ inch in diameter.

The Dubois-François Rock-Drill.—The design, mode of action, and construction of the Dubois-François rock-drill are founded upon those of Sommeiller's machine; but the improvements effected are of such a character as to render the former greatly superior to the latter. In consequence of this superiority it has superseded its prototype, and firmly established itself in favour upon the Continent, but especially in Belgium and in France. Its general employment in these two countries, the importance of the work to which it has been applied, and the protracted character of the tests to which it has been subjected, are sufficient evidence of its merits. The design and construction of this machine are shown in Figs. 301 to 304, Plate XXIII., and its mode of action will be understood from the following description, and the illustration afforded by the drawings.

The percussion piston B reciprocates in a cylinder O. The rod A of this piston is of comparatively large dimensions, and is provided at its lower extremity with an enlarged section pierced to receive the cutting tool. The valve gear is altogether of a special character. An ordinary slide-valve G is connected to two pistons H and H′, each moving in a cylinder provided for it. The piston H′, it must be observed, has a larger surface area that the piston H. When the compressed air enters the valve-chest, it exerts a pressure upon both pistons, which pressure tends to force them in contrary directions. But as the area of H′ is greater than that of H, the pistons, being connected by their rods and the valve, move forward. This motion opens the port *x*, air is admitted above the piston B, and the drill-bit is driven against the rock. The piston H′, however, is pierced by a small passage *i i*, which allows the compressed air to pass to the other side of it in J, by which means equilibrium is restored upon the two surfaces. When this equilibrium is established, the action of this piston is destroyed, and, consequently, the pressure acting upon the other piston H, forces the pistons in the contrary direction. This motion opens the port *z*, air enters below the piston B, and the drill-bit is withdrawn from the rock. To cause this action of the pistons to be repeated, an annular projection C, upon the rod A, comes in contact during the back stroke with a lever D, which, being raised, opens the valve E. The air in the space J escapes, and the equilibrium of the piston H′ is thereby destroyed.

It will be seen that the action of this valve gear throws the motive force suddenly upon the percussion piston for the forward or working stroke, while it effects the return stroke in a less violent manner. The size of the air passage through the valve-piston H′ is a matter of importance. To determine the most suitable proportions, many experiments were needed. If this passage were too large, equilibrium would be established too soon, and a consequent jerky motion would be produced in the percussion piston; if it were too small, the motion of the latter would be too slow and irregular. The results of experiments have shown that to obtain a perfectly satisfactory action in a machine of the dimensions given in the drawing, the passage should be 0·1 inch in diameter.

The rotation of the drill-bit is obtained by the alternate action of two small pistons P and P′, Fig. 303. These pistons, which are single acting, receive compressed air through the opening *m*, *n* upon the ports of the percussion piston. The alternating action thus obtained is transmitted by a rigid rod Z to a ratchet-wheel V, Fig. 304, fixed upon the rod A, in the fore part of the machine. By this means the rotation of the bit is accomplished in a satisfactory manner at a cost of only a small quantity of air. The feed motion is communicated by hand by means of a screw, as shown in the drawings.

The principal dimensions of the machine are as follows: Total length, 7 feet 2 inches; weight, 484 lb.; diameter of the cylinder, $2\frac{1}{2}$ inches; diameter of the piston-rod, $1\frac{1}{2}$ inch; maximum stroke, $7\frac{3}{4}$ inches; weight of the striking mass, including 8-lb. borer-bit, 68 lb.; length of feed, $31\frac{1}{2}$ inches.

If this machine drill be examined relatively to the conditions previously laid down, it will be found that it only partially satisfies the first. Though extremely simple in some of its parts, an unnecessary degree of complexity is occasioned by the presence of no less than five pistons. Those which actuate the rotating gear also appear to be too much exposed to injury from dirt and gritty water. The ratchet gear being exposed, is liable to injury from blows and strains otherwise caused, and to be impeded in its action by grit. The second, third, and fourth conditions are not complied with. The fifth condition is fully satisfied. The sixth is only partially satisfied, inasmuch as the percussion piston is liable to strike against the cylinder covers. The valve gear being totally independent of the motion of the piston, there is no means of preventing this accident, and as a matter of fact it continually occurs at the back stroke of the piston. To lessen the destructiveness of the blow upon the cylinder cover, the latter is usually protected by an elastic cushion of indiarubber or guttapercha. In consequence of the independent action of the valve gear, the seventh condition is perfectly satisfied, the length of stroke being capable of variation from the maximum down to $\frac{3}{4}$ of an inch. This constitutes a great advantage at the commencement of a bore-hole. The eighth condition, like the sixth, is not satisfied; the ninth is complied with; and the eleventh and twelfth are fulfilled in a fairly satisfactory degree.

It appears, therefore, that this machine is more suitable for employment in headings at surface, such as are driven in excavating railway tunnels, than in ordinary underground mining operations, in which the unfulfilled conditions are of paramount importance.

The Sachs Rock-Drill.—The machine rock-drill known by the name of its inventor, Carl Sachs, is widely employed in Germany, where it has executed very important work. The ingenuity and refinement evinced in the design and construction of this machine claim careful attention.

The Sachs drill is shown in section and in end elevation, in Figs. 305 to 308, Plate XXIII. As the details of construction are therein clearly shown, a general description of the action will be suffi-

cient to make it fully understood. The slide-valve, it will be observed, is of the ordinary character, and the mode of admitting, cutting off, and exhausting the motor fluid precisely the same as in an ordinary steam-engine. The valve is worked by a bell-crank lever connected with the piston-rod in the manner shown in the drawing. Thus the motion of the valve is wholly dependent upon that of the piston. It will be observed that ample clearance space is provided at each end of the cylinder. To give the requisite rotary motion to the tool, another arm of the rocking lever communicates a reciprocating motion to a rod, shown partly in Figs. 305 and 306, but more fully in Fig. 307. Upon this rod are fixed two ratchet-pawls held up against the teeth of a ratchet-wheel upon a cylindrical piece, through which the rod passes at the upper end of the percussion cylinder. This cylindrical piece is provided on the inside with a groove in which a rib upon the rod slides. The action of the pawls in causing the wheel to revolve will be apparent from the drawing. The feed motion is communicated by hand in the usual manner by means of a screw and crank handle, or wheel, as described in Dubois-François machine. This is the mode of feeding adopted in what is known as the "low-pressure" machine. In the "high-pressure" machine, which is made of smaller cylinder dimensions, the feed is made automatic by connecting the mechanism with the rotating gear.

The following are the principal dimensions of the machine: Total length, 23 inches; weight, 100 lb.; diameter of cylinder, $2\frac{1}{2}$ inches; diameter of back piston-rod, 1 inch; diameter of forward piston-rod, $1\frac{1}{2}$ inch; maximum length of stroke, 4 inches; weight of the striking mass, including 8-lb. borer-bit, 24 lb.; length of feed, $18\frac{1}{2}$ inches.

If this machine be considered in relation to the afore-given conditions, it will be found that it fails to satisfy the first and the second. There is a considerable degree of complexity in the design, and many of the parts are exposed. Hence we should expect that when subjected to the ordinary conditions of work, it would be liable to frequent derangement; and as a matter of fact the inference is true. No machine could work more satisfactorily than the Sachs so long as the circumstances are favourable, and the various parts remain in perfect order; but the rough usage of actual practice speedily occasions a necessity for repairs. The third, fourth, fifth and sixth conditions are fully satisfied. The complete dependence of the motion of the slide-valve upon that of the piston, and the ample clearance allowed at each end of the cylinder, effectually remove any tendency that might exist for the piston to strike the cylinder covers. A large amount of clearance is usually condemned as wasteful of the motor fluid. Such an opinion is, however, an erroneous one. It is true that the quantity of fluid represented by the cubic capacity of the clearance space is not utilized upon the rock, but it is utilized in a very effective manner upon the machine. A rock drill cannot be compared with an ordinary engine. The circumstances under which it has to work are such as tend to cause its rapid destruction; and if this tendency can be considerably lessened by the expenditure of a small additional quantity of fluid at each stroke, such an expenditure ought to be regarded as a true economy. It costs less to generate a little more steam, or to compress a little more air per hour, than to have a machine constantly in the repairing shop, a store of spare machines at hand as a provision against breakage, and, which is still more important, continual delays at the working face.

The seventh condition is not fulfilled by the Sachs drill. The connection between the slide-valve and the piston is such that the latter must always make its full stroke. The eighth and ninth conditions are fulfilled, but the tenth is not satisfied. The automatic feed takes place in a regular manner,

the forward motion proceeding by a certain definite quantity at each stroke of the piston. The eleventh condition is not satisfied in the high-pressure machine, and the twelfth neither in that nor in the low-pressure machine.

The Burleigh Rock-Drill.—The Burleigh machine-drill, which is of American origin, claims attention by reason of its having been employed in the important work of excavating the Hoosac tunnel. Since that time it has been somewhat largely applied to mining operations, and with a considerable degree of success. This machine, which is shown in the sections, Figs. 309 and 312, consists essentially of a cylinder A, a piston B, with its rods, and a valve gear *a*, *b*. Both the back and forward piston-rods pass through stuffing boxes in the cylinder; to the forward rod the borer-bit is fixed by the means shown in Figs. 309 and 310; the back rod, which is made smaller in diameter than the forward rod, to give a larger piston area on that side, terminates in an annular protuberance. This protuberance on the piston-rod is intended to strike alternately during its reciprocating motion the back and forward arms of the tappet lever *a*, to which the rod of the slide-valve is attached. It will be evident that the rocking motion of the lever thus produced will communicate the requisite reciprocating motion to the valve, and by this means the desired action of the piston is ensured. To effect the rotary motion of the latter, the back piston-rod is provided with a spiral feather, which works in a corresponding groove in a cylindrical piece fitting into the back portion of the cylinder. This cylindrical piece is provided on the outside with teeth, thereby forming a kind of ratchet-wheel, as shown in Fig. 312. A detent held up by a spring prevents the piece from turning in one direction, but allows it to revolve freely in the contrary direction. By this means the piston is made to turn partially round during the back stroke; but during the forward stroke the piston turns the cylindrical piece before described, the motion of which in that direction is unrestrained by the detent. The forward motion of the cylinder, or feed motion, is effected automatically by means of the screw F, actuated by suitable mechanism. This feed-screw passes through a gallows-frame M, affixed to the back end of the bed-plate, and again through a feed-nut into the cylinder. The end of the piston is drilled out, in order that the feed-screw may not be struck by the former during its oscillations. The feed-nut is secured between two collars in a manner to allow of easy revolution, and its outer edge is cut into a ratchet, into which works a pawl actuated by the piston. The turning of the nut by this means upon the fixed screw moves the cylinder forward. The mechanism by which this is accomplished is shown in Figs. 311 and 312. When the tool has penetrated the rock, and the piston consequently advanced nearer the front cylinder cover, the protuberance upon the back piston-rod strikes against the catch *d*, and thereby releases the lever *e*. The latter is then forced inwards by a spring, so as to be struck by the head of the piston at the return stroke, by which means it is again restored to its original position. The other end of the lever being connected to the pawl before mentioned, the feed-nut is turned by the extent of one tooth. This action is repeated as the penetration of the tool progresses. Frequently the automatic feed gear is omitted from the construction, and the necessary motion communicated by hand.

The principal dimensions of this machine are the following: Total length, 51 inches; weight, 166 lb.; diameter of cylinder, $2\frac{3}{4}$ inches; diameter of back piston-rod, $1\frac{3}{4}$ inch; diameter of forward piston-rod, $2\frac{1}{4}$ inches; maximum length of stroke, $4\frac{1}{2}$ inches; weight of the striking mass, including 8-lb. borer-bit, 34 lb.; length of feed, 22 inches.

An examination of the Burleigh machine relatively to the conditions previously enunciated will show that it does not satisfactorily fulfil the first and the second of those conditions. There exists

considerable complication of parts, and many of the parts are of a fragile character. The striking gear by which the valve is actuated would appear to be liable to very rapid wear and frequent derangement. Also its exposed situation on the outside of the machine must tend to favour the occurrence of such results. The mechanism for producing the automatic feed is of a delicate and somewhat complicated character. The third and the fourth conditions are fairly, and the fifth perfectly satisfied. The sixth condition is not fulfilled, inasmuch as the tappet gear is exposed to violent shocks. The seventh condition is not satisfied. The eighth condition is fairly complied with; the ninth and tenth are fully satisfied. The eleventh condition is not fulfilled, and the twelfth is fulfilled in only a fairly satisfactory manner.

The Kainotomon Rock-Drill.—The Kainotomon machine-drill was introduced as an improvement upon the Burleigh, and a glance at its parts will show that the design and construction of that machine have been greatly simplified. The Kainotomon has been extensively employed in mining and quarrying operations. The variety of the work to which it has been applied has furnished a severe test of its suitability for the purpose for which it is designed, and it would appear from report that it has undergone this test in a satisfactory manner. The quality which above all others is recommendatory of a machine rock-drill is durability, and durability is mainly dependent upon simplicity. Judged from this point of view, the Kainotomon should be greatly superior to the Burleigh. The machine will be found illustrated on Plate XXIV. Fig. 314 is a front elevation of the cylinder; Fig. 313 is a longitudinal section through the machine; Fig. 315 is a cross section showing the valve in position; Fig. 316, an elevation showing the valve face with cover removed; and Figs. 317 and 318 represent different views of the valve.

The Kainotomon rock-drill consists essentially of a cylinder A, a piston and piston-rod B C, and the valve gear at F. The valve F, shown in Figs. 313 and 315, is pivoted at H; it has an arm G, the projection *f* on which is struck by the two pistons alternately during the reciprocating motion of the latter; by this means the requisite motion is communicated to the valve. The motor fluid is admitted through *k* and the ports *g g*, Figs. 313 and 316, and exhausted through the port *h*. The rotation of the tool is effected by the same means in the Kainotomon as in the Burleigh machine, the position only of the parts being changed. The piston-rod passes through a cylindrical piece D, called the rotation tube, placed in the neck of the cylinder, and held in position by the washer D′. This tube is provided with a spiral slot *a*, in which works a projection or feather *b* in the piston-rod. On the upper end of the tube D are ratchet-teeth *c*, into which is forced the pawl *d* by means of a spring *e*, the pawl and spring being held in position by the gun-metal cap *d′*. The teeth and pawl are arranged so as to compel the piston-rod to rotate during the backward stroke, and to allow it to turn freely during the forward stroke. In the forward end of the cylinder is an elastic packing-ring E′, which is held in position by a steel washer E; this packing ring serves as a buffer to mitigate the destructive effects of the blow should the piston strike against the forward end of the cylinder. The feed motion is communicated by hand, by means of the feed-screw L, which runs parallel with the cylinder, and is held by the lugs M M cast upon the cylinder. The machine slides in the jacket T. The universal clamp U deserves special attention, as it allows the machine to be turned in any direction, and to be fixed upon the cylindrical bar V, by simply tightening the set-screw W, which acts upon the gripping plates *i* and *k*, and the washer *m*.

The following are the principal dimensions of the machine: Total length, 36 inches; weight, 205 lb.; diameter of cylinder, $3\frac{1}{2}$ inches; diameter of piston-rod, 2 inches; maximum length of

stroke, $4\frac{3}{4}$ inches; weight of the striking mass, including 8-lb. borer-bit, 53 lb.; length of feed, 18 inches.

Considered relatively to the conditions necessary of fulfilment, the Kainotomon will be found to satisfy the requirements of the first and the second in a manner that leaves but little to be desired. The construction is extremely simple; there is no outside gear to be exposed to injury, and the moving parts consist only of the piston and the valve. The third condition is not fulfilled. The fourth and the fifth conditions are fully satisfied; but the sixth is not wholly complied with, as the valve is subjected to violent shocks from the blows of the pistons. This defect prevents the attainment of a high piston velocity, and not unfrequently results in the valve being knocked off the face. The seventh condition is fulfilled in a fairly satisfactory manner. The eighth condition is not satisfied, inasmuch as the forward piston is liable, under the circumstances indicated, to strike against the forward end of the cylinder. There is no clearance space allowed at this end of the cylinder; but there is, as already described, an elastic packing-ring, which tends greatly to mitigate the destructive effects of the blows struck. The remaining conditions, with the exception of the tenth, which does not apply in this case, as the feed motion is communicated by hand, are completely fulfilled.

The McKean Rock-Drill.—The characteristic peculiarities of the McKean machine drill are shown on Plate XXV., Figs. 315 to 318. Besides the anterior piston-rod to which the tool is attached, there is a posterior rod which passes through the back end of the cylinder, and is prolonged through the valve and feed-gear chamber situate behind the cylinder. Upon this prolongation of the rod is an enlargement or a swelling of an ovoid form, as shown in Fig. 315. During the reciprocating motion of the piston, this enlarged portion strikes alternately the arms l and l' which hang upon the opposite sides of the piston-rod. By this means an oscillating motion is produced in the rod upon which the arms are fixed, which motion is communicated to the valve; the form and action of which will be understood from the drawings. To give the requisite rotary motion to the tool, the enlarged portion of the piston-rod is provided with spiral teeth which gear into corresponding spiral teeth on a rotary cam-spindle o. This cam-spindle is provided with a ratchet-wheel which is held by a pawl, so that the cam may turn only in one direction, namely, during the backward stroke of the piston. To produce the feed motion, a ratchet-wheel q is placed loosely upon the feed-screw n. This wheel is connected by means of the arm q' with the arm or lever l' upon the valve-rod, as shown in Fig. 315, and by this means the oscillating motion of the latter is communicated to the wheel. This motion is transmitted to a crown ratchet-wheel p, which is held up to the wheel q by a spring, and by means of which the cylinder is moved forward upon the feed-screw n. Such are the general and distinctive features of the McKean drill as applied in the St. Gothard tunnel. A lighter form of this machine is made; but as the proprietor has thought it desirable to withhold information concerning the details of its construction, we are unable to consider it here, or to enter more minutely into the design of the form we have illustrated. This action is the more to be regretted, as it points to inferences of an unfavourable character.

The following are the principal dimensions of the McKean drill: Total length, 38 inches; weight, 150 lb.; diameter of cylinder, 3 inches; diameter of anterior piston-rod, 2 inches; diameter of posterior piston-rod, $1\frac{1}{4}$ inch; maximum length of stroke, 4 inches; weight of the striking mass, including 8-lb. borer-bit, 32 lb.; length of feed, 12 inches.

An inspection of the figures on Plate XXV., illustrative of the McKean drill, will show that it fulfils the first four conditions in a fairly satisfactory manner. The fifth condition is fully satisfied;

the sixth fairly. The seventh condition does not appear to be fulfilled. The remaining conditions, except the tenth, are satisfactorily complied with. The tenth is clearly violated, as the feed motion, being communicated by the lever which actuates the valve, is continuous. Sometimes the McKean drill is constructed to be fed forward by hand ; and in this case the rotary motion of the tool is taken from the feed motion : thus the tenth condition is violated in this construction also.

The Ingersoll Rock-Drill.—The Ingersoll machine-drill is of recent introduction, and as an improvement upon many pre-existing machines of a like character, it possesses numerous claims to notice. The designers of this drill have evidently kept in view the conditions under which rock-perforating machinery has to work, and they have succeeded in fulfilling the requirements in an eminently satisfactory degree. The peculiarities of the Ingersoll drill will be rendered apparent by the following description of its design and construction, and the illustrations upon Plate XXV.

In Figs. 319 to 321, E is the cylinder, M the piston, and L the piston-rod. The valve gear is actuated by the piston through the medium of tappets, and consists of a slide-valve M′, two valve rods or spindles B, and two tappet levers H. The action of this valve gear and of the piston needs no description. The rotary motion of the tool is obtained by means of the spirally grooved bar S recessed into the back end of the piston. A cap screwed into the piston is provided with studs or feathers to run in the grooves of the bar. On the end of the latter is a ratchet-wheel, into the teeth of which a pawl is held by a spring. This pawl, as in the case of some of the machines already described, forces the piston to turn during the back stroke, but allows the spiral bar to rotate during the forward stroke. The forward motion of the cylinder, or feed motion, is produced automatically in the following manner. As the tool penetrates the rock, the piston approaches the forward end of the cylinder, and strikes against a tappet lever H′, which partially rotates the rod R in the manner shown in Fig. 319. This rod turns, by means of pawls and ratchet-teeth, a nut upon the back end of the cylinder, through which nut passes the feed-screw P, as shown at V. The rotation of this nut upon the fixed feed-screw causes the cylinder to advance.

The following are the principal dimensions of this machine: Total length, 30 inches; weight, 155 lb.; diameter of cylinder, $2\frac{3}{4}$ inches; diameter of piston-rod, 2 inches; maximum length of stroke, 4 inches; weight of the striking mass, including 8 lb. borer-bit, 26 lb.; length of feed, 19 inches.

If the Ingersoll drill be considered relatively to the conditions laid down on a foregoing page as necessary of fulfilment, it will be found to satisfy the whole of them, with the exception of the sixth, in a more or less complete degree. The design and the construction are simple and strong, and the moving parts are few in number. By the use of two tappet levers rocking through a small arc, the violence of the shock produced by the blow delivered at each stroke of the piston is much lessened, and the durability of the parts proportionately increased. Another contrivance for ensuring durability in the valve-gear consists in making the spindles B separate from the valve and from the tappet levers. This expedient has been found in practice to act very satisfactorily. An ample clearance space is provided at the forward end of the cylinder, but there is none at the back end. Hence there is no liability of the piston striking the front cylinder cover, but this liability exists for the back cover. To lessen the destructive effects of the blow, however, an elastic cushion is provided. Thus it will be seen that the sixth condition is not satisfied. Judged by this standard, the Ingersoll appears to be an excellent machine; and there can be no doubt that, by its numerous and great merits, it is destined to occupy a foremost place among rock drills.

The Darlington Rock-Drill.—The Darlington rock-drill is remarkable as the attainment of the

highest degree of simplicity of parts possible in a machine. The valve gear of a machine drill is especially liable to derangement. It must necessarily consist of several parts, and these parts must as necessarily be of a somewhat fragile character. Besides this, when actuated by the piston through the intervention of tappets, the violence of the blow delivered at each stroke is such as to rapidly destroy the parts. In some of the machines already described, the force of these blows and their destructive tendency have been reduced to a minimum ; but when every means of remedying the evil has been employed, there remains a large amount of inevitable wear and tear, and a liability to failure from fracture or displacement exists in a greater or less degree. Moreover, as these effects are greatly intensified by increasing the velocity of the piston, it becomes at least undesirable to use a high piston speed. To remedy these defects, which are inherent in the system, J. Darlington proposed to remove altogether the necessity for a valve gear by radically changing the mode of admitting the motor fluid to the cylinder. This proposal he has realized in the machine which we have now to consider, and which will be found illustrated on Plate XXVI.

The Darlington rock-drill consists essentially of only two parts: the cylinder A, Fig. 322, with its cover; and the piston B, with its rod. The cover, when bolted on, forms a part of the cylinder; the piston-rod is cast solid with the piston, and is made sufficiently large at its outer end to receive the tool. These two parts constitute an engine, and with less than one fixed and one moving part, it is obviously impossible to develop power in a machine by the action of an elastic fluid. The piston itself is made to do the work of a valve in the following manner: The annular space affording the area for pressure on the fore part of the piston gives a much smaller extent of surface than that afforded by the diameter of the cylinder, as shown in Fig. 322 ; and it is obvious that, by increasing or diminishing the diameter of the piston-rod, the area for pressure on the one side of the piston may be made to bear any desired proportion to that on the other side. The inlet aperture or port C being in constant communication with the interior of the cylinder, the pressure of the fluid is always acting upon the front of the piston; consequently, when there is no pressure upon the other side, the piston will be forced backward in the cylinder. During this backward motion the piston first covers the exhaust port D, and then uncovers the equilibrium port E, by means of which communication is established between the front and back ends of the cylinder, and consequently the fluid made to act upon both sides of the piston. The area of the back face of the piston being greater than that of the front face by the extent occupied by the piston-rod, the pressure upon the former first acts to arrest the backward motion of the piston, which by its considerable weight and high velocity has acquired a large momentum, and then to produce a forward motion, the propelling force being dependent for its amount upon the difference of area on the two sides of the piston. As the piston passes down, it cuts off the steam from the back part of the cylinder and opens the exhaust. The length or thickness of the piston is such that the exhaust port D is never open to its front side; but in the forward stroke it is open almost immediately after the equilibrium port is closed, and nearly at the time of striking the blow. It will be observed that the quantity of fluid expended is only that which passes over to the back face of the piston, since that which is used to effect the return stroke is not discharged.

The means employed to give a rotary motion to the tool are deserving of special attention, as being simple in design, effective in action, and well situate within the cylinder. These means consist of a spiral or rifled bar H, having three grooves, and being fitted at its head with a ratchet-wheel G, recessed into the cover of the cylinder. Two detents J J, Fig. 324, also recessed into the

cover, are made to fall into the teeth of the ratchet-wheel by spiral springs. These springs may, in case of breakage, be immediately renewed without removing the cover. It will be observed that this arrangement of the wheel and the detents allows the spiral bar H to turn freely in one direction, while it prevents it from turning in the contrary direction. The spiral bar drops into a long recess in the piston, which is fitted with a steel nut, made to accurately fit the grooves of the spiral. Hence the piston during its instroke is forced to turn upon the bar; but during its outstroke it turns the bar, the latter being free to move in the direction in which the straight outstroke of the piston tends to rotate it. Thus the piston, and with it the tool, assumes a new position after each stroke.

The following are the principal dimensions of the Darlington drill: Total length, 36 inches; weight, 100 lb.; diameter of cylinder, $3\frac{1}{2}$ inches; diameter of piston-rod, $2\frac{1}{2}$ inches; maximum length of stroke, 4 inches; weight of the striking mass, including 8-lb. borer-bit, 35 lb.; length of feed, 24 inches.

The mode of fixing the cutting tool to the piston-rod is a matter deserving some attention. As the tool has to be changed often more than once during the progress of a bore-hole, it is important that the change should be accomplished in as short a time as possible; and as the vibration of the machine and the strain upon the tool are necessarily great, it is equally important that the tool be firmly held. It is also desirable that the mode of fixing the tool shall not require a shoulder upon the latter, a slot in it, or any peculiarity of form difficult to be made in the smithy. If the foregoing machines be compared in this respect, it will be found that the Darlington fulfils the requirements of expedition in fixing, firmness of retention, and simplicity of form most satisfactorily. The means and the method are the following: The outer end of the rod or holder is first flattened to afford a seat for the nut, as shown in Figs. 322 and 327. The slot is then cut and fitted tightly with a piece of steel K, forged of the required shape for the clamp, and the holder is afterwards bored to receive the tool while the clamp is in place. This clamp K is then taken out, its fitting eased a little, and its end screwed and fitted with a nut. When returned to its place in the holder, the clamp, in consequence of the easing, can be easily drawn tight against the tool, by which means it is firmly held in position. The shank of the tool is turned to fit the hole easily, and the end of it is made hemispherical to fit the bottom of the hole, upon which the force of the reaction of the blow is received.

If the Darlington drill be considered relatively to the conditions laid down as necessary to be fulfilled, it will be found not only that it satisfies the whole of them, but that it satisfies them in the most complete manner. It would seem impossible to attain a higher degree of simplicity of form, or to construct a machine with fewer parts. The absence of a valve or striking gear of any kind ensures the utmost attainable degree of durability, and allows a high piston speed to be adopted without risk of injury. As the piston controls its own motion, there is no liability to strike against the cylinder cover. The stroke may be varied in length from half an inch to 4 inches, and as the machine will work effectively with a pressure of 10 lb. to the inch, holes may be started with the greatest ease. With a pressure of 40 lb., the machine makes 1000 blows a minute, a speed that may be attained without causing undue strains or vibration. This alone constitutes a very great advantage. It must, indeed, be conceded that a careful consideration of the merits of this drill shows it to be admirably adapted to the work required of it, and leads inevitably to the conclusion that it is the most perfect machine for rock boring that has yet been produced.

The Warsop Rock-Drill.—The Warsop machine-drill claims special attention on account of certain peculiarities of design of a strongly characteristic nature. The designers of this drill have re-introduced, under greatly improved conditions, a principle long since abandoned. Schwarzkopf was the first to construct a rock-perforating machine in which the cutting tool was detached from the piston-rod, and in which it was struck by the latter after the manner of a steam hammer. The principle thus adopted is, as we have already shown, false, and as the general design of Schwarzkopf's machine was defective, it failed to establish itself in favour. This is the principle that Messrs. Warsop and Hill have reintroduced; but they have so modified and improved the general design and construction of the machine as to make it superior to many of its predecessors in which the tool is made to reciprocate with the piston. This fact does not, however, render a false principle true; and it should be acknowledged that from this point of view the design of the Warsop machine is defective. But it is claimed by the inventors, and it must also be acknowledged that their statements in this respect are in some degree true, that the adoption of the principle of the hammer involves the introduction of advantages which compensate any loss due to that principle. The nature of these advantages will be described when we come to consider the machine relatively to the conditions previously laid down as necessary of fulfilment.

The design and construction of the Warsop machine will be found illustrated upon Plate XXVI. Fig. 328 being a longitudinal section of the drill; and Fig. 329 a front elevation of the same.

In Fig. 328 C is the cylinder or main body and frame of the machine, cast in one piece. An inner cylinder or casing D fits accurately into the cylinder C at its upper part, and is free to partially rotate in cylinder C. In the top of casing D is firmly fixed a twisted bar E of a flat section. This bar passes through a disc of steel F firmly fixed in the piston G, down the centre of which a hole is bored to receive the full length of the twisted bar. At the opposite end of the piston-rod A is firmly cottered a head H having two wings h^1 h^2, fitting grooves cast in the frame C, and capable of sliding freely up and down them. The head H is made to strike at each blow an anvil I, having a recess at its lower part made to receive a drill or chisel. The end of the anvil is formed with a rim round it, against which the end of the main body rests: this rim of anvil I has teeth cut round its periphery, into which gears a smaller toothed wheel J, formed in one piece with the rod K and handle L, in such a manner that by turning the handle L the drill inserted in I will be rotated.

The reciprocating action of the piston G is as follows: In the casing D four narrow longitudinal portways are cut, shown in Fig. 328. These slots correspond, one at the top and one at the bottom at opposite sides of the casing, with corresponding portways in the cylinder C, and in such a manner that when the casing is partially turned round, one port at the top and one at the opposite side at the bottom are closed, and the other two are open. Steam or air is admitted to the cylinder through opening B, passes alternately through port 2 or 1 into the casing D, forces the piston G up and down; the steam or air exhausting alternately through ports 3 and 4, and out at the passage A. The partial rotation of the casing D in the cylinder, and consequent regulation of the steam or air and exhaustion from the interior, is effected by the reciprocating motion of the piston G, which is prevented from turning round by the wings h^1, h^2, causing the bar E to turn partially backwards and forwards at each stroke in the disc F. By this means the piston G and anvil H are made to give a succession of rapid blows on the anvil I, and consequently to the drill point, which is constantly being turned round by the handle L, the machine itself being prevented from turning round by a sleeve in which it slides, carried by the support upon which it rests.

In order to obtain increased simplicity of construction, the feed is made automatic. When boring downwards, it is obvious that the machine will follow the tool as the latter penetrates the rock. The same result is obtained when boring in an upward direction by means of a counterweight suspended over a pulley fixed upon the support upon which the machine rests.

The following are the principal dimensions of the machine: Total length, 24 inches; weight, 80 lb.; diameter of cylinder, 4 inches; diameter of piston-rod, 3 inches; maximum length of stroke, 4 inches; weight of the striking mass, 40 lb.

Considered relatively to the conditions which every rock drill is required to fulfil, the Warsop machine will be found to satisfy the first four in a very complete manner. Of the fifth, the first part, which requires the striking mass to be relatively of great weight, is satisfactorily fulfilled; but the second part, which requires this striking mass to strike the rock directly, is violated. It has already been demonstrated that the loss of *vis viva*, due to the separation of the tool from the piston, increases as the weight of the tool increases, and as the weight of the striking mass decreases. In the Warsop drill, the weight of the anvil upon which the hammer-headed piston-rod strikes must be added to that of the tool attached to it, and hence calculation will show that the loss of work due to this cause must be very considerable. We are therefore compelled to view the principle adopted as constituting a grave defect; and we are also impelled, by the unquestionable merits of the machine, to express our opinion that by the removal of this defect the machine would be rendered a very efficient one. It is, however, claimed by the designers that when the ordinary method of reciprocation is adopted, the friction of the tool against the rubbish in the hole, or against the sides of the hole when the machine support has been shaken a little out of position, is very great, often amounting, indeed, to more than the work of actual boring, and that by the adoption of the principle of the Warsop drill this loss is not incurred. This estimate of the value of the friction, which is doubtless considerable, is certainly excessive; and though it may perhaps be proved that in certain cases the loss by friction occasioned in this way is equal to that due to the principle adopted in the design of the machine, it is difficult to see what is really gained.

The remaining conditions, with the exception of the ninth, are satisfactorily fulfilled. The non-fulfilment of the ninth constitutes another defect. It has been proved upon a preceding page that the rotation of the drill shall, rather than the feed, take place automatically. In the Warsop machine, the rotary motion is communicated by hand, while the feed is made automatic. Moreover, the nature of this feed motion is objectionable. The counterweight, by constituting a heavy load to remove from place to place, and occupying considerable space when suspended in position, tends to destroy the advantages of light weight and small dimensions in the machine itself. Also the use of this counterweight would seem to militate against the attainment of perfect freedom of position in the support, and of expedition in removing the machine from one situation or position to another.

The Diamond Rock-Drill.—The diamond drill, the principle and the construction of which were explained and described when treating of deep borings, has been successfully applied to boring for ordinary blasting purposes. As this machine cannot under existing arrangements be used by any other than the Diamond Rock-Drill Company, who undertake to perform the work by contract, it does not seem desirable to illustrate its construction. Such illustration, moreover, appears the less necessary, as the principle of the diamond drill, unequalled as it is for deep prospective borings, is less suitable for the ordinary purposes of shaft-sinking and heading driving than that upon which

the machines described in the foregoing pages act. For such work, the diamond will probably fail to hold its ground against the percussive machines.

It will appear that, when judged by the standard which we have adopted, the foregoing machine drills differ widely in point of merit. Some are constructed upon principles and in a manner that are at variance with the conditions of work to which they must necessarily be subjected; while others, embodying the teachings of experience, fulfil every requirement in a manner that leaves little to be desired. There can be no reasonable doubt that the latter are destined not only to occupy alone the field at present shared by the inferior machines, but to do important service in expediting mining operations, and in thereby promoting, in no insignificant degree, the prosperity of mining enterprise. Arranged according to their fulfilment of the conditions necessary in a rock drill, the machines previously described appear in the following order, which order will be observed in the subsequent table of dimensions: The Darlington, the Ingersoll, the Kainotomon, the Warsop, the McKean, the Sachs, the Burleigh, and the Dubois-François.

Borer-Bits.—The form and the dimensions of the cutting tools, variously described as "drills," "borers," and "bits," used in machine rock-perforators, are matters of great practical importance, and therefore deserving of careful attention. The dimensions are determined mainly by two conditions, namely, the necessity for sufficient strength in the shank of the tool, and the necessity for sufficient space between the shank and the sides of the hole to allow the débris to escape. Experience has shown that these two conditions are best fulfilled when the distance between the sides of the hole and the shank of the tool is from $\frac{3}{16}$ inch to $\frac{1}{4}$ inch. The form of the cutting edge is affected by several conditions. The form first adopted was very naturally that possessed by hand drills, namely, the chisel edge, which was sometimes made straight, and sometimes bowed. It was then attempted to increase the useful effect of the machines, and especially the rapidity of the boring, by enlarging the surface of the cutting edge. This was first effected by forming the bit of two chisel edges crossing each other at right angles, and called therefrom the "cross" bit. The tool thus constructed was found to effect the object desired in a very satisfactory manner at the commencement of the boring, when there was a free surface to strike upon; but as the boring progressed in depth its action became less and less effective, owing to its form preventing the ready escape of the débris. To remedy this defect, the cutting edges were made to cross each other obliquely, so as to form the letter X, and called therefrom the X bit. By this means the two chisel edges were retained, while the breadth of the bit was considerably reduced. This form cleared the hole much more effectively than the cross, but yet not in a sufficiently satisfactory manner to warrant its general adoption. Another modification of the form was therefore made, and this time that of the Z was adopted, the upper and lower portions of which were arcs of circles struck from the centre of the bit in the direction contrary to that of the rotation. With this form of tool, the hole cleared itself readily of the débris. But besides this advantage, which was the only one sought, others of an important character were involved. With the forms thitherto adopted, the corners of the bit were rapidly worn off by friction against the sides of the hole. With the Z form this wearing no longer occurred, by reason of the comparatively large surface exposed to the friction. Another advantage possessed by the Z form of bit lies in its tendency to bore the hole truly circular. It is evident that the single chisel-edge bit may rotate in a hole, not only when it is circular in section, and of a diameter equal to the width of the edge, but also when the section is a curvilinear triangle, constructed upon an equilateral triangle, the side of which is equal to the width of the edge, and each summit of which is the centre

of a circular arc of 60° passing through the other two. Again, and more generally, the section might be a polygon composed of an odd number of curvilinear sides, each of which was an arc of a circle described from the opposite summit, as a centre, with a radius equal to the width of the cutting edge. This tendency to deviate from the circular form of section in the bore-hole was found to be completely corrected by the adoption of the Z bit; and hence it has come to pass that this form of cutting edge is now generally employed. It must not, however, be inferred from this statement that the other forms have been altogether abandoned; on the contrary, they are constantly employed under those conditions to which they have been proved suitable. Thus, the cross-bit is well adapted for the purpose of starting a hole, and for boring in fissured rock, and the single chisel-bit may be used with advantage in rock of a very hard nature. Also, generally, each of the various structures and textures of rocks will be found to yield more readily to one form of cutting edge than another, and these circumstances afford occasion for the application of knowledge and the exercise of judgment.

The sharpening of bits of a form other than that of the single chisel is effected by means of "swages." The tempering is performed in the way already described in reference to hand drills. As in the latter case, both the degree of temper and the angle of the cutting edge should be determined according to the hardness of the rock to be penetrated. The percussive action of the tool in machine drills appears to be admirably suited to its nature, since it has been found by experience to lead to this remarkable result, namely, that for a given length of boring, executed far more rapidly than by hand, the wear of the cutting edge is five or six times less. The saving of steel due to this cause constitutes one source of economy in machine boring. The quality of the steel used for borer-bits should be the best procurable, since it will be found conducive both to rapidity of boring and to economy of cost to employ the most suitable material. Sometimes the shank is of wrought iron; but more often the tool consists wholly of steel, the bars from which it is cut being usually octagonal in form. The cost of these bars has been given in another place. As in the case of hand-boring, each successive length of tool must diminish slightly in the width of its cutting edge, for reasons that have been already explained. The diminution need not be great; about $\frac{1}{32}$ of an inch may be considered sufficient. Care must, however, be taken to ensure the proper dimensions being given to the edge, and it will be advantageous to possess an accurate gauge through which the tool may be passed previously to its being fixed in the machine. It is also important that the tool should be truly *centered*, that is, the centres of the edge of the bit, of the shank, and of the piston-rod, should be perfectly coincident. It may be observed here that it will be found conducive to rapid progress to have an abundant supply of bits always ready at hand.

The Stretcher Bar.—The stretcher bar has been already alluded to as fulfilling most completely the requirements of a machine-drill support. Such a bar is represented on Plate XXVII., Fig. 330. In this bar, which is that used with the Darlington drill, rigidity and lightness are combined in the highest possible degree by adopting the hollow section. The stretcher bars used with the other machines are similarly constructed.

Economy of Machine Drilling.—It was stated on a former page that the substitution of machine for hand drilling led rather to a saving of *time* than of *money*. This remark had reference solely to the machines that have been for some time in use. With those of recent introduction, in which the numerous imperfections of the early perforators do not exist, the saving of cost may be made fully equal to the saving of time. Increased simplicity of construction must notably reduce the annual outlay in repairs, which, together with the cost occasioned by the consequent delays, has hitherto

formed so large a proportion of the working expenses; and increased facilities for boring in any desired situation or position must lead to a diminished consumption of explosive compounds. Hence we may reasonably expect that as improved methods are adopted, and greater skill, the result of more extensive knowledge, is applied, the proportionate cost of excavating by machinery will be lessened in a marked degree.

ROCK-BORING MACHINES—COMPARATIVE TABLE OF DIMENSIONS.

	1 Darlington.	2 Ingersoll.	3 Kainotomon.	4 Warsop.	5 McKean.	6 Sachs.	7 Burleigh.	8 Dubois-François.
Total length of the machine, borer-bit not included	in. 36	in. 30	in. 36	in. 24	in. 38	in. 23	in. 51	in. 86
Weight of the machine complete, without the borer-bit	lb. 100	lb. 155	lb. 205	lb. 80	lb. 150	lb. 100	lb. 166	lb. 480
Internal length of the cylinder	in. 11	in. 11	in. 15	in. 8	in. 7	in. 8	in. 6½	in. 12½
Diameter of the cylinder	3½	2¾	3½	4	3	2½	2¾	2½
Length of the piston	—	6	8	2½	2	2¾	1¼	3¼
Effective posterior area of the piston	9·62	5·94	9·62	12·56	5·85	4·13	3·54	4·91
„ anterior „ „	4·71	2·80	6·48	5·49	3·93	3·15	1·97	3·14
Maximum stroke of the piston	4	4	4¾	4	4	4	4½	7¾
Weight of the striking mass—piston, piston-rod, and 8-lb. bit	lb. 35	lb. 28	lb. 53	lb. 40	lb. 32	lb. 24	lb. 34	lb. 68
Volume of air expended in the forward stroke	in. 38·48	in. 23·76	in. 45·69	in. 50·24	in. 23·40	in. 16·52	in. 15·93	in. 48·05
Volume of air expended in the back stroke	0·0	11·20	30·77	21·96	15·72	12·60	8·86	24·33
Volume of air lost on account of clearance space	14·43	2·80	20·86	15·30	4·99	5·04	1·86	5·16
Volume of air expended for each blow	52·91	37·76	97·32	87·50	44·11	34·16	26·65	77·55
Force of propulsion with pressure of 30 lb.	lb. 182·3	lb. 206·2	lb. 341·6	lb. 416·8	lb. 207·5	lb. 171·3	lb. 140·2	lb. 215·3
Force of repulsion with pressure of 30 lb.	106·3	56·0	141·4	124·7	85·9	70·5	25·1	26·2
Nature of the feed motion	hand	automatic	hand	automatic	automatic	automatic	automatic	hand
Length of feed	in. 24	in. 19	in. 18	—	in. 12	in. 18	in. 22	in. 32

Compressed Air as a Motor Fluid.—The employment of compressed air as a means of transmitting force may be regarded as one of the most remarkable mechanical achievements of the present times. No doubt as a means of utilizing distant and yet unavailable sources of force, the importance of this medium can hardly be over-estimated, for it is abundantly clear that it possesses qualities which may render it productive of immense benefits in that direction. But it is in its application to mining purposes, which afford the most favourable opportunities for its employment, that it is destined to undergo its complete development and to attain its highest degree of usefulness. To the altogether exceptional nature of the situations in which mining operations are carried on, the peculiar character of these operations themselves, and the otherwise difficult conditions under which they have to be performed, the qualities of compressed air render it particularly suitable. Its easy conveyance to any point of the underground workings, and its ready application at any point; the improvement which it produces in the ventilative currents; the complete absence of heat in the reservoir and conducting pipes, a condition which tends greatly to their preservation; these and numerous other advantages, when contrasted with the defects of steam under like conditions, give to compressed air a value which the mining engineer will fully appreciate. In applying a motor fluid

underground, it is rather a question of distributing small forces over a large number of points, than of concentrating a large force at one or two points. This is particularly the case when it becomes necessary to employ hauling engines, coal-cutting machines, and portable rock-drills, the positions of which are daily changing. To satisfy conditions such as these, compressed air is alone admissible.

Great, however, as the merits of compressed air as a medium for transmitting force are, it possesses defects of an important character. These defects, which have been strangely overlooked, lie chiefly in its inherent and essential qualities as a gas, whereby a loss of the force to be transmitted is occasioned. The amount of the loss due to this source is necessarily considerable; but when due precautions are not taken to keep it near its minimum limits, it may assume very grave proportions. There can be no reasonable doubt that the best machines and appliances now in use for the compression of air are excessively wasteful of the motive force. This excessive loss must be attributed to two causes: first, to a mistaken notion respecting the position held by air-compressing engines among machinery; and second, to a general want of attention to the mechanical properties of air.

It would seem to be assumed that air-compressing machines are mere temporary expedients, to be erected for a time at a given place, and then removed to another. Hence small dimensions, portability, and, above all, cheapness, have been the objects chiefly aimed at, to the sacrifice of efficiency and the obstruction of improvement. It will be vain to look for a realization of the highest attainable degree of perfection in the machinery designed for the production of compressed air, until such machinery is viewed as constituting a portion of the permanent plant of a mine, to be protected by suitable buildings, entrusted to competent hands, and in every way as attentively cared for as the winding engines themselves. When compressing machines are regarded in this light, air will begin to assume its proper development as a medium for the transmission of force. The second cause alluded to, namely, the marked want of attention to the mechanical properties of air, may, perhaps, be considered the natural concomitant of the first. Hence we may expect that when the one has been removed, the other will speedily follow. Indirectly dependent upon the former cause, the latter is, however, directly due to a general ignorance of the principles of thermo-dynamics. Thus it becomes desirable to expound briefly these principles in so far as they affect the application of compressed air to practical purposes. It would be beyond the scope of the present work to enter into these questions abstractedly and in detail, or to discuss the means of determining with absolute precision the values of given quantities under all conditions: such considerations find their place in special treatises. But it will be found useful to place clearly before the mind of the engineering student the fundamental principles of the subject, and to furnish him with the means of ascertaining, with a degree of approximation sufficiently near for practical purposes, the value of the phenomena which occur in an air-compressing machine.

The Thermo-Mechanical Properties of Air.—In considering the properties of permanent gases, that is, gases which, as far as our present knowledge extends, cannot be liquefied by the application of cold and pressure, there are three variable quantities to be taken into account, namely, the *volume* of the gas in question; the *elastic force* exerted by it, or what amounts to the same thing, the *pressure* necessary to retain it in that volume, and its *temperature.* These quantities, as it will hereafter appear, are to a great extent dependent upon one another.

Volume.—By volume is understood the space, measured in cubic feet occupied by a unit, as 1 lb. of air, at any given moment.

Pressure.—By pressure is understood the weight in pounds avoirdupois required upon every square foot of surface to retain the air in a given volume. This pressure, it must be borne in mind, includes the weight of the atmosphere, which is assumed to be in all cases 14·70 lb. upon the square inch, the actual weight when the mercurial barometer stands at 29·92 inches.

Temperature.—By temperature is understood the number of degrees measured by Fahrenheit's scale on a perfect gas-thermometer, from a zero 461°·2 below the zero of Fahrenheit's scale, that is, 493°·2 below the freezing-point of water. This zero-point is that at which the elastic force of air would completely disappear.

To illustrate the application of the foregoing terms, suppose a pound of air, a mean atmospheric pressure of 14·7 lb. to the square inch, and a temperature of 60° Fahr. Under such conditions, 1 lb. of air will occupy a space of 13·09 cubic feet; and if we represent the volume by v, the pressure by p, and the temperature by t, we shall have, $v = 13 \cdot 09$, $p = 14 \cdot 7 \times 144 = 2116 \cdot 8$, and $t = 461 \cdot 2 + 60 = 521 \cdot 2$.

Conditions of Equilibrium.—It is known that for a unit of weight of air, or any perfect gas, the product of the pressure and the volume, divided by the temperature, remains unaltered through all conditions of change. That is, $\frac{p\,v}{t} = c$, or $p\,v = c\,t$, c being a constant, which for air has the value, 53·15.

It now remains to show the relation existing between any two of the variable quantities when the third is made constant. And here we confront three important and well-established laws, which are the following:

I. If the *volume* be made constant, the pressure will vary directly as the temperature. Symbolically expressed, if $p\,t$ represent the initial pressure and temperature, and $p_1\,t_1$ the same quantities changed in degree, then $\frac{p_1}{p} = \frac{t_1}{t}$.

II. If the *pressure* be made constant, the volume will vary directly as the temperature. That is, if $v\,t$ and $v_1\,t_1$ represent the volumes and temperatures, $\frac{v_1}{v} = \frac{t_1}{t}$.

III. If the *temperature* be made constant, the volume will vary inversely as the pressure. Or, expressed symbolically as before, if $p\,v$ and $p_1\,v_1$ represent the pressures and volumes, $\frac{v_1}{v} = \frac{p}{p_1}$.

As illustrations to these laws, suppose the following examples: First, if a pound of air at atmospheric pressure and 60° Fahr. be retained in a closed vessel and heat applied to the latter, the pressure of the enclosed air will be doubled when the temperature has been doubled. That is, the initial temperature being $461 \cdot 2 + 60 = 521 \cdot 2$, the pressure will be doubled when the temperature has been increased to $521 \cdot 2 \times 2 = 1042 \cdot 4$, or when the Fahrenheit thermometer marks $1042 \cdot 4 - 461 \cdot 2 = 581 \cdot 2$ degrees.

Second, if the air be retained in a cylinder in which is a piston free to move as the air expands, and heat be applied, the volume of the enclosed air will be doubled when the temperature has been doubled. That is, the initial temperature being 521·2 degrees absolute as before, to double the volume the temperature must be increased to $521 \cdot 2 \times 2 = 1042 \cdot 4$, or to $1042 \cdot 4 - 461 \cdot 2 = 581 \cdot 2$ degrees Fahr.

And third, if it be required to reduce the volume of the air in the cylinder to one-half that

which it possesses at any given, say atmospheric, pressure, when means are adopted to keep the temperature constant, the pressure must be doubled. That is, if the air in the cylinder occupy a space of one cubic foot, to compress it into a space of half a cubic foot, a pressure of $2116 \cdot 8 \times 2 = 4233 \cdot 6$ lb. to the square foot must be exerted.

Specific Heat.—It is known that if a certain quantity of heat will raise the temperature of a body one degree, twice that quantity will raise its temperature two degrees, three times the quantity, three degrees, and so on. Thus we may obtain a measure of heat by which to determine either the temperature to which a given quantity of heat is capable of raising a given body, or the quantity of heat which is contained in a given body at a given temperature. The quantity of heat requisite to produce a change of one degree in temperature is different for different bodies, but is practically constant for the same body, and this quantity is called the specific heat of the body. The standard which has been adopted whereby to measure the specific heat of bodies is that of water, the unit being the quantity of heat required to raise the temperature of 1 lb. of water at its greatest density 1° Fahr., that is, from 39° to 40°. The quantity of heat required to produce this change of temperature in 1 lb. of water is called the "unit of heat," or the "thermal unit;" and as heat and work are mutually convertible, it is evident that work may be expressed in thermal units, or, if so desired, heat may be expressed in foot-pounds. The mode of measurement by thermal units possesses the advantage of leading to the employment of smaller numbers than the other; but the foot-pound is, on the whole, the more convenient unit. The value of the thermal unit has been indisputably proved by Joule to be equivalent to 772 foot-pounds. In other words, a weight of 772 lb. falling through a height of 1 foot generates sufficient heat to raise the temperature of 1 lb. of water 1° Fahr., assuming that the whole of the heat so generated could be collected and applied to that purpose. Or, conversely, the heat given out by 1 lb. of water in cooling 1° is sufficient to raise 772 lb. through a height of 1 foot, assuming that the whole of the heat so given out could be collected and employed in doing work.

Having determined the specific heat of water, that of air may in like manner be ascertained and expressed either in terms of the former or in foot-pounds. It has been proved by exhaustive experiments, that if air be heated at constant pressure through 1° Fahr. measured on the air-thermometer, the quantity of heat absorbed is $0 \cdot 2375$ thermal units, or $772 \times 0 \cdot 2375 = 183 \cdot 35$ foot-pounds, whatever the pressure or the temperature of the air may be. Thus the specific heat of air at constant pressure is, measured in foot-pounds, $183 \cdot 35$. Similarly, it has been shown that the specific heat of air at constant volume is, in thermal units, $0 \cdot 1687$ nearly, or in foot-pounds, $772 \times 0 \cdot 1687 = 130 \cdot 20$. Hence the ratio of the specific heat of air at constant pressure to that at constant volume is $\frac{183 \cdot 35}{130 \cdot 20} = 1 \cdot 408$, or, for practical purposes, say $1 \cdot 41$. We now observe that the difference of the two specific heats of air is $53 \cdot 15$; that is, it is equal to c in the foregoing equation of equilibrium. Thus, if K_p represent the specific heat of air at constant pressure, and K_v the specific heat at constant volume, both expressed in foot-pounds, we have the relation $K_p - K_v = c$.

Conversion of Heat into Work.—We now come to the important consideration of the conversion of heat into work. As a convenient illustration, frequently employed, of what takes place in such a case, suppose a cylinder of 1 square foot sectional area, and of indefinite length, fitted with a balanced air-tight piston; and assume that the piston stands at a height of $13 \cdot 09$ feet from the bottom of the cylinder; then, if the temperature be 60° Fahr., the cylinder will contain 1 lb. of air, and the pressure upon the piston will be that of the atmosphere only, that is, $2116 \cdot 8$ lb.

First, let the piston be fixed, and let heat be applied to the cylinder until the temperature of the contained air has been doubled, that is, until it has been raised from 60 + 461·2 to 2 (60 + 461·2) degrees absolute. The volume being in this case constant, the pressure will by Law I. be doubled; that is, the pressure exerted against the piston and tending to force it upwards will be 2116·8 lb. in excess of that of the atmosphere tending to force it downwards. Also the quantity of heat expended to produce this change will be 130·2 × 521·2 = 67,860 foot-pounds; and in cooling down to the original temperature this quantity of heat will be given out. In this case no work is done, the whole of the heat expended has been employed in raising the temperature of the air.

Second, let the piston be free to move, and let 67,860 foot-pounds of heat be applied to the pound of air contained in the cylinder. In this case, the pressure being constant, the air will expand and force up the piston through a height equal to 19·3 feet, where it will stand at a height of 22·38 feet above the bottom of the cylinder, the experiment thus showing that the volume of the air has increased in the ratio of $\frac{13\cdot09}{9\cdot3} = 1\cdot71$. Also, in accordance with Law II., the temperature will have increased in the same proportion, and therefore will be 521·2 × 1·71 = 891·2, the increase of temperature being 891·2 − 521·2 = 370 degrees. The quantity of heat absorbed in producing this change of temperature is 130·2 × 370 = 48,174 foot-pounds, leaving 67,860 − 48,174 = 19,686 foot-pounds to be accounted for. The air in expanding has forced up the piston through a height of 9·3 feet against an atmospheric pressure of 2116·8 lb., and thus has done work equal to 2116·8 × 9·3 = 19,686 foot-pounds, the exact equivalent of the heat which has disappeared. Hence it is evident that of the 67,860 units of work applied in the form of heat, 19,686 have manifested themselves as external work, and 48,174 have been absorbed in raising the temperature of the air to the degree required by the increased volume necessary to perform that amount of work.

Suppose now an additional quantity of heat applied until the temperature has been doubled. Then by Law II. the volume will have been doubled also, and the work done upon the piston will be 13·09 × 2116·8 = 27,709 units, which represents an expenditure of heat to that amount. To double the temperature there will be required 67,860 foot-pounds of heat, as already shown, and the effect produced by this quantity of heat may be called the internal work. Hence the total quantity of heat expended will be equal to the internal work + the external work = 67,860 + 27,709 = 95,569 units of work, = $K_p\,521\cdot2 = 183\cdot35 \times 521\cdot2$; and the external work may be expressed as $c\,521\cdot2 = 53\cdot15 \times 521\cdot2$. From this it will be evident that the internal work is always $K_v\,(t_1 - t_2)$ where t_2 and t_1 are the temperatures at the beginning and the end respectively of the change produced, and that we may readily find the quantity of heat expended in producing any change in a pound of air, since: Heat expended = internal work + external work = $K_v\,(t_1 - t_2)$ + external work = $K_v \frac{p_1 v_1 - p_2 v_2}{c}$ + external work, which is the general equation of the action of heat in a perfect gas.

Heat Expended in the Expansion and Compression of Air.—We have now to consider the important practical question of the quantity of heat expended in the expansion and compression of air. Let A B, Fig. 331, be a cylinder, in which moves an air-tight piston P; and let the dimensions of the cylinder be such that when the piston is in the position $m\,n$, the weight of the contained air at mean atmospheric pressure and 60° Fahr. temperature shall be 1 lb. Then, assuming that the temperature is kept constant, when the piston is moved forward to the position $m'\,n'$ the volume of the air will be reduced to one-half, and its pressure increased to two atmospheres. Suppose

now a body X, at a temperature of $60° = t_1$, and capable of communicating an indefinite quantity of heat, to be put in communication with the cylinder A B, and the piston to be set in motion towards its first position $m\,n$. As the position moves on, the volume of the air increases, and if no heat were communicated the temperature would fall; but as the body X is in contact with the cylinder, which is supposed to be a perfect conductor, the slightest depression of the temperature below t_1 causes heat to flow from X into the air, and thus the temperature is maintained constantly at t_1. During this operation the air expands at constant temperature, and the question to be determined is: What quantity of heat has been abstracted from the reservoir of heat X? for this is the quantity expended by the expansion of the air. The expansion curve in such a case being a common hyperbola, it can be shown that this quantity of heat $= p\,v \log. r = c\,t_1 \log. r$, r being the ratio of expansion, and the logarithm being hyperbolic. Thus, H representing the quantity of heat expended, we have

$$H = c\,t_1 \log. r.$$

Suppose now the body X to be removed, and another body X_1 of the same temperature, and capable of receiving an indefinite quantity of heat, to be placed in contact with the cylinder, and let the piston be again moved forward towards $m'n'$. As the piston travels forward the air is compressed, and if no heat were abstracted the temperature would rise; but as the body X_1 is in contact with the cylinder, the slightest elevation of the temperature causes heat to flow from the air into X_1, and thus the temperature is maintained constantly at t_1. During this operation the air is compressed at constant temperature, and the quantity of heat rejected into X_1 is equal to that abstracted from X; that is, it is equal to $c\,t_1 \log. r$. Thus, representing the quantity of heat expended during compression by H_1, we have

$$H_1 = H = c\,t_1 \log. r.$$

In this case, the equality of H and H_1 is necessary and evident. And it may be remarked that the quantity of heat H_1 rejected during compression, which is equal to H the quantity abstracted during expansion, is the exact equivalent of the work done upon the air in the cylinder by the piston in the forward or compressing stroke. In this example, we have an instance of the conversion of work into heat. The action of an engine working in this way is to pump heat from the body X into the body X_1, and when this view of the action is taken, the equality of the quantities becomes manifest.

In the case we have supposed, the value of $H_1 = 19{,}197$ foot-pounds. Let this quantity of heat, which has been forced into X_1 during the motion of the piston, towards $m'\,n'$, be restored to the air when the piston has reached the latter position, assuming the pressure of the piston to be constant. The effect of the application of this quantity of heat will be to raise the temperature of the air $\frac{H_1}{K_p} = \frac{19{,}197}{183 \cdot 35} = 104 \cdot 7$ degrees, that is, from $t_1 = 521 \cdot 2$ degrees to $t_2 = 625 \cdot 9$ degrees absolute. But as the volume varies as the temperature when the pressure is constant, the volume A $m'n'$ B will be increased in the proportion of $0 \cdot 2$, which is the ratio of $104 \cdot 7$, the increase of temperature, to $521 \cdot 2$, the original temperature. Thus the original volume being 1, the new volume due to the increased temperature will be $1 \cdot 2$; in other words, the piston will be forced back from the position $m'\,n'$, to the position shown by the dotted lines at $o\,o$, and the volume of air at the pressure of two atmospheres will be A $o\,o$ B, instead of A $m'\,n'$ B as before. Suppose now the cylinder to be placed in communication with a reservoir R by means of the valve V, the pressure of the air in the reservoir being two atmospheres, and additional force applied to the piston. As the pressure in the cylinder and in the reservoir is in equilibrium, it is obvious that as the piston advances the volume

A $o\,o$ B will be forced into the reservoir, where means are provided for keeping the pressure constant. Now, so far, it matters not whether we force into the reservoir the volume A $m'\,n'$ B at t_1 temperature, or the volume A $o\,o$ B at t_2 temperature, since the work of the heat H_1 applied is stored up in the increased volume. But as it is practically impossible to keep the temperature of the air in the reservoir above that of the surrounding atmosphere, this quantity of heat H_1 will escape, and the greater volume will diminish to the lesser without doing any work. Hence it will be seen that the restoration of the heat abstracted will occasion a loss of work equal to that which is represented by the external work of that quantity of heat. And it is also evident that if the heat be allowed to accumulate during compression, the effect will be practically the same as that produced by restoring it after compression. It follows, therefore, that in the compression of air under these conditions, there must necessarily be an important loss of motive force, and that this loss is greater as the degree of compression is greater.

In the work of compressing air in practice, the surrounding atmosphere is the body X, from which heat is abstracted by the backward stroke of the piston; and water, applied in various ways, is the body X_1, into which the heat is forced by the forward stroke. If it were possible to apply water in such a way as to fully satisfy the conditions demanded in the assumed body X_1, there could be no accumulation of heat, and, consequently, no loss of work due to this source.

There yet remains for consideration a matter of some practical importance. Suppose, again, the piston to travel forward to the position $m'\,n'$, while the body X_1 is in contact with the cylinder. The air occupying the volume A $m'\,n'$ B will then be of the same temperature as $X_1 = t_1$. Let the body X_1 be then removed, and the piston allowed to travel back to the position $m\ n$. The conditions are now such that no heat can be received by the air, and, consequently, as it expands, its temperature will fall. It is required to know by how much the temperature has fallen when the piston has arrived at the position $m\ n$. When a gas expands at constant temperature, which is the case we have had under consideration, the expansion curve is a common hyperbola; but when it expands in a non-conducting, non-radiating cylinder, which is the case we have now to consider, the expansion curve is of a form called the adiabatic, the equation of which is $p\,v^\gamma =$ constant, γ being the ratio $\frac{K_p}{K_v}$ 1·41 of the specific heat at constant pressure to that at constant volume. Suppose the gas to expand from v_1 to v_2, and let its corresponding pressure and temperature be $p_1\ t_1$ and $p_2\ t_2$. Then we have $p_1 v_1 = c\,t_1$; $p_2 v_2 = c\,t_2$; $p_1 v_1^\gamma = p_2 v_2^\gamma$. Hence $c\,t_1\,v_1^{\gamma-1} = c\,t_2\,v_2^{\gamma-1}$; or,

$$t_2 = t_1 \left(\frac{1}{r}\right)^{\gamma-1}$$

This equation, in which r is the ratio of expansion, shows by how much the temperature falls for any given expansion.

In employing compressed air for driving machinery, as machine rock-drills, for example, this fall of temperature is attended with important consequences. When low pressures are used, the coolness produced in the atmosphere of underground workings by the expansion of the compressed air is highly conducive to the salubrity of such situations; and when high pressures are employed, great inconvenience is occasioned by the excessive cold produced, the water contained in the air being frequently frozen and deposited as ice in the exhaust passages of the machine.

Loss of Work in Compressing Air.—The most important source of loss of work in compressing air is the accumulation of heat. If the foregoing expositions have been fully understood, there should be no difficulty in estimating its precise value in any case. The means of remedying the evil lies in

the application of a suitable medium of abstraction. Hitherto water has shown itself to be the most effective and convenient body for such a purpose, and numerous modes of applying it have been devised, in order to obtain the best possible results. To favour the action of the water, the velocity of the piston should be kept low. This would appear from the foregoing considerations to be a necessary condition of efficiency. The mode of applying water as a jet within the cylinder must necessarily be the most effective, and designers of air-compressing machines will therefore do well to direct their efforts to the improvement of the means whereby this mode of application is effected.

Another source of loss of work, the consequences of which increase in importance with the degree of compression, is the clearance space at the end of the cylinder. These consequences will, on reflection, become sufficiently apparent. Suppose a cylinder in which the compression is carried to six atmospheres. When the piston arrives at the end of its stroke, the clearance space contains air compressed into one-sixth of its volume at atmospheric pressure; and it is obvious that when the piston recedes, this air must expand into six times that volume, that is, into its volume at atmospheric pressure, before any air from the surrounding atmosphere can enter the cylinder; that is, in other words, before the suction-valve can open. Thus a volume of air is lost at each stroke equal, at atmospheric pressure, to that assumed by the compressed air in the clearance space when, by expansion, it has dropped to the same pressure. To remove altogether the necessity for a clearance space, columns or cushions of water have been employed, in a manner which will be described hereafter. These fulfil the purpose required very satisfactorily; but it must be borne in mind that they are themselves a source of loss of work, by the inertia which they oppose to the motive force. It should be remarked that the contents of the clearance space includes the air in the receiver behind the valve, which air returns into the cylinder as the valve closes. This is called the slip of the valve, that is, the quantity of air which the valve as it returns to its seat allows to slip back into the cylinder. When the lift of the valve is great, this quantity may be considerable; and when the lift is slight, the resistance from friction, due to the contracted passages, may also be considerable.

Leakage of the valves and pistons and the friction of the moving parts constitute sources of loss of greater or less importance according to the degree of perfection attained in the construction of the machine, and the condition in which it is maintained. As these sources of loss are greatly dependent for their existence upon design, workmanship, and supervision, they are capable of being reduced to narrow limits. It is, however, needful to remark here that the loss of work due to the friction of the air in the valve-ways, and to the influence of the contracted vein, is by no means insignificant.

There is yet another source of loss of motive force, the influence of which is very great, and which increases with the degree of compression. This source of loss, which has been singularly neglected, exercises an important bearing upon the question of economy relatively to this mode of transmitting force, and is therefore deserving of careful consideration. As the air has to be compressed by the application of force, it is clear that the fraction of that force which remains after the important deductions have been made for the losses already described, cannot be fully recovered without working the air expansively down to the pressure of the atmosphere. As this is in all cases impracticable, there must be always a loss of work, the value of which may be determined from the degree of expansion adopted. In the case of machine rock-drills, which work without expansion altogether, the loss is necessarily very great, and, when high pressures are used, may become enormous. This question is obviously an important one, and it will undoubtedly exert a modifying influence upon the design of machines to be driven by compressed air.

Loss of Work in Transmission.—Compressed air has to be conveyed in pipes and tubes from the reservoir into which it has been forced, to the machines in position at the various points where operations are being carried on, through distances in many cases considerable. During this transmission, a loss of work is occasioned by the friction of the air in the pipes. Numerous and exhaustive experiments have been made to determine accurately the value of the loss thus occasioned. From the results of these experiments, the following three conclusions have been deduced, namely, 1, that the resistance is directly as the length of the pipe; 2, that it is directly as the square of the velocity of flow; and 3, that it is inversely as the diameter of the pipe. Upon these results and conclusions formulæ have been established whereby the value of the loss of force may be ascertained with ease and accuracy. These formulæ show that for pipes of the diameters usually employed for this purpose, and for distances not exceeding one mile, the loss of motive force due to the friction of the air in the pipe is insignificant when the velocity does not exceed 4 feet a second. And it can be shown that even this loss is notably diminished, and in some cases entirely annulled, by the increased head due to the depth of the shaft, when the compressed air is employed in mines. The influence of this head may often be taken advantage of to diminish slightly the diameter of the pipes, and thereby to effect a considerable economy of cost. As this source of loss of motive force is of small moment when compressed air is applied to ordinary mining operations, so long as the velocity is kept below the limit already mentioned, it is unnecessary and undesirable to discuss here the formulæ by means of which its value may be determined, or to illustrate the manner of their application. The consideration of this question will therefore be deferred to a subsequent chapter.

It becomes apparent from the foregoing investigations that compressed air as a medium of transmission is, under the most favourable conditions, exceedingly wasteful of the motive force, and that the waste may become enormous if means are not employed to keep it near its minimum limits. The application of such means involves conditions which can be satisfied only when the machinery employed for the compression is designed to form a portion of the permanent plant of a mine. Even with machinery of this character as at present constructed, not more than 30 per cent. of the motive force remains to be utilized when the necessary deductions for loss have been made; and calculations for practical purposes ought, therefore, to be based upon this, or a smaller proportion. It will be found instructive to compare the results of carefully conducted experiments with a compressor constructed on the principle adopted by Sommeiller at the Mont Cenis tunnel, and applied, with improvements of detail, to supply the rock-boring machines employed at the Sarrebruck mines, which results have been tabulated by the engineer, M. Pernolet, as follows:

No. of the Experiment.	Revolutions a Minute.		No. of Revolutions in the Engine required to give in the Receivers an Excess of Pressure of			Useful Effect of the Compressors at		
	Engine.	Compressor.	One Atmosphere.	Two Atmospheres.	Three Atmospheres.	One Atmosphere.	Two Atmospheres.	Three Atmospheres.
1	14·83	5·51	108	230	359	0·94	0·88	0·85
2	21·26	7·90	107	229	356	0·95	0·885	0·855
3	29·76	11·06	109	231	358	0·93	0·88	0·85
4	35·20	13·09	107	226	352	0·95	0·90	0·865
5	44·62	16·59	108	234	367	0·94	0·87	0·83
6	48·50	18·03	109	238	380	0·93	0·85	0·80

The compression cylinder was in this instance 0·393 metre = 15·47 inches in diameter, and the length of the stroke was 1·255 metre = $49\frac{1}{2}$ inches. The ratio of the gear being 29 : 78, one revolution in the compressor corresponded to 2·69 in the engine. During the first four experiments there was no sensible elevation of temperature in the valve-box; but in the fifth an increase of temperature became apparent; and in the sixth this increase was very marked. It will be remarked that up to thirty-five revolutions of the engine, corresponding to 13·09 of the compressor, = 21·5 inches a second, the useful effect remains independent of the velocity; but that beyond this it diminishes notably as the velocity increases. In consequence of the results obtained from these experiments the maximum velocity of the compressors was fixed at eighteen revolutions a minute, = $29\frac{1}{2}$ inches a second. The ordinary speed, however, was hardly more than half this.

Construction of Machines for Compressing Air.—It now remains to illustrate the foregoing theoretical remarks by a detailed description of the most approved machines for compressing air actually in use. In the fulfilment of the conditions demanded, Continental engineers appear to have been the most successful, and for this reason our descriptions will relate mainly to machines of their design. In consequence of the important tunnelling operations which have been carried on upon the Continent, more favourable opportunities have been there afforded for studying the requirements of compressed air, and hence arises the superiority of design. If the mechanical properties of air expounded in the foregoing pages be borne in mind, there should be no difficulty in understanding the principles involved in the construction of the machines to be described, or in appreciating their merits and defects. In treating of them, therefore, it will be sufficient to limit our remarks to description only.

In nearly all recent instances in which compressed air has been applied on an important scale, preference has been given to water-column compressors, in which the piston acts upon the air through the medium of a mass of water that rises at each stroke to the delivery valve, and thereby reduces the clearance space to zero, while the air is kept saturated with water during the compression. But such machines, in which there is always a considerable mass of water in motion, must necessarily be driven at a low speed, and hence, when large volumes of compressed air are required, recourse must be had to increased dimensions. This necessity involves a large outlay, and this outlay often constitutes an insuperable difficulty in the way of adopting rock-boring machinery. Many attempts have been made to remove this defect by omitting the column of water, and thereby allowing the piston to act directly upon the air to be compressed. Few of these attempts have, however, proved sufficiently successful to justify the adoption of the system. In most of the compressors so designed the air becomes greatly heated, notwithstanding the precautions taken to prevent such a result. There are, however, some notable instances in which success has been achieved in an eminent degree, and these instances are deserving of special and careful consideration by reason of the important results to which they lead. Of these, the compressor in use at the St. Gothard tunnel, and known, from the name of its inventor, as Colladon's machine, is the most noteworthy.

Air-Compressors at the Sarrebruck Collieries.—We have already had occasion to allude to the satisfactory results obtained from the air-compressors used at the Sarrebruck collieries. The design and construction of these compressors, as well as the general arrangements adopted, are shown in Figs. 332 and 333. The motor is a horizontal expansion steam-engine, the cylinder of which is $24\frac{3}{4}$ inches in diameter, with a stroke of 43 inches. With a pressure of 45 lb., and a cut-off at half stroke, this engine develops, at fifty revolutions a minute, a nominal force of 170 horse, in round

numbers. But with the compressors at present in use, it is found to be sufficient to drive the engine at twenty-five revolutions a minute under a pressure of only 30 lb., the force developed under these conditions being about $54\frac{1}{4}$ horse. This engine communicates motion to a shaft, from which the compressors are driven by spur gear. This shaft is designed to admit of being lengthened for the purpose of driving two additional compressors when the workings are more fully developed. Besides the compressors, the engine drives, by means of belting, a lathe and a boring machine in an adjoining workshop erected for the repair of the rock drills. The whole arrangement will be understood from the drawings. The advantage of transmitting the force developed upon the steam piston through the medium of gearing lies in the arrangement allowing the engine to be run at a higher speed; and with a higher speed a less weight in the fly-wheel becomes sufficient. Moreover, when an engine working expansively is connected directly to the compressors, the greatest resistance in the compression cylinder occurs when the tension of the steam is least, and *vice versâ*, a defect that is removed by the adoption of intermediate gear.

The compressors are constructed upon the principle, first adopted by the Italian engineers at the Mont Cenis tunnel, by which any heating of the air is prevented and clearance space avoided, by interposing a column of water between the piston and the air to be compressed. In this construction, we have upon each of the two faces of a piston moving horizontally a column of water of a certain height, which ascends and descends as the piston advances and recedes. During the descent of the column the air is drawn into the space left free by the water, and during the ascent of the column this air is compressed and forced into the receiver. The water being driven close up to the delivery valve there is little or no clearance space; and as the water acts as a packing for the piston, as well as a cooling medium, there is no leakage or heating of the piston, cylinder, or valves. Figs. 332 and 333 are a plan and a sectional elevation of this machine, in which the piston is at half stroke.

The piston of the compressor is $15\frac{1}{2}$ inches in diameter, and 12 feet in length; its form is that of a hollow plunger, and it has a thickness of cast iron of 1 inch; it is turned on the outside, and closed at its two ends. This piston moves on each side in a cylinder 5 feet in length, and $20\frac{1}{2}$ inches in diameter. Over the middle of the cylinder is a tubular outlet, 33 inches in diameter and 5 inches in height, upon which is bolted a valve chest or chamber 27 inches in depth. The whole thus forms, at each end of the piston, a column rising to a height of 33 inches above a horizontal cylinder.

The two cylinders, or pump-barrels, are separated from each other by a horizontal distance of 6 feet, measured from stuffing box to stuffing box. In this space travels between guides an iron cross-head fixed upon the piston, to which cross-head the two connecting rods are attached by which the motion is communicated to the piston. The length of the stroke is 4 feet. Within the valve chamber are two annular spaces, formed by the valve seating and the cover. The space below the seating contains the air drawn in from the atmosphere, and the space between the seating and the cover contains the compressed air. The construction of these points will be best understood by reference to the drawings. It should be remarked, however, that both the suction and the delivery valves are of indiarubber.

The action of this compressor is as follows: As the plunger recedes, the column of water above it sinks, the suction valve opens, and the space vacated by the water is filled with air. When the piston returns, the suction valve closes, the column of water rises into the space it previously occupied, and compresses the air in it till the pressure is sufficient to open the delivery valve, when the air is

forced into the annular space above, and thence into the receiver. The quantity of water is so calculated that when the piston has arrived at the end of its stroke, the column reaches the delivery valve, and consequently the whole of the air is expelled. To replace the water which is carried off by the air, a constant supply is brought in above the suction valve through a pipe $\frac{1}{2}$ inch in diameter. This water enters the cylinder while the valve is open, and the excess is driven off through the delivery valve along the air-conduit into the receiver. This excess of water serves to cool the air; the requisite degree of opening of the cock upon the supply pipe for a given piston velocity is soon shown by experience.

The compressed air enters a horizontal pipe 6 inches in diameter, connecting the two pumps of each compressor. From the middle of this pipe, another of the same diameter rises to a height of 6 feet, and then becomes horizontal till it reaches the reservoir. Beneath the point at which the latter pipe enters the former is a *well* to catch the water carried along by the compressed air. A small tube, half an inch in diameter, conducts the water back to the reservoir. For the purpose of emptying the cylinders in case of repairs being required, a discharge cock is placed near the bottom. As a considerable quantity of the water is carried into the air receiver, the same automatic apparatus is applied to the bottom of the receiver as to the well below the pipe. This apparatus is shown in section in Fig. 334. It consists of a copper float *a a* open at the top, and capable of motion, in a cast-iron vessel *d d*, closed by a screwed cover; the motion of this float actuates a double-beat valve by means of the rod *b*. The water entering through *e* accumulates in the annular space *d d*, and the float *a a* rises and closes the valve. But as the water continues to enter, it flows over and into the float, and thereby causes it to descend again; the valve consequently opens again, and the pressure of the air acting upon the water inside the float forces it out through the central tube *f f*. This water passes through the valve *v*, and thence along the passage *g* to the cold water reservoir. As soon as the float is emptied it rises, and the same effects are reproduced. There is always sufficient water in the float to keep the end of the ascension tube closed. To allow the air to escape, a small opening *h* is provided. This ingenious contrivance works very regularly, and when the compressors are driven at their normal speed the water is discharged in a nearly continuous jet. Thus the only supply of fresh water needed is that which is lost by evaporation.

It becomes necessary now and then to cleanse this apparatus of the impurities brought in by the water. For this purpose the cock which isolates it from the receiver or the compressor is closed, and the valve removed by means of the screw and stirrup shown at *i*. This operation occupies less than ten minutes. To clean the apparatus more completely the cover must be removed.

These compressors, as already shown, work very satisfactorily; but their construction is somewhat expensive, and they occupy a considerable space.

Air-Compressors at the St. Gothard Tunnel.—Colladon's air-compressor, the general arrangement of which is shown in Figs. 335 to 341, consists of a horizontal cylinder having a hollow piston, the rod of which, also hollow, passes through both ends of the cylinder, the suction and discharge valves being placed in the cylinder covers. The peculiarity in the construction of this compressor consists in the means adopted for cooling those parts of the apparatus which are brought into contact with the compressed air. These means, which are very ingeniously arranged, are: a circulation of water around the cylinder and through the cylinder covers, piston, and piston-rod; and an injection of water, in the form of spray, into the two ends of the cylinder. The circulation of the water in the cylinder covers and around the cylinder is effected

by means of a small pump placed at the side of the cylinder, the plunger of which takes its motion from the cross-head of the compressor piston-rod. This pump forces the water, through copper tubes having an internal diameter of about $\frac{3}{4}$ inch, into the spaces *a a* cast in the thickness of the cylinder covers, and into the annular space *b b* formed between the cylinder and its outer casing or jacket; and the water passes off through similar tubes situate in the bottom of the cylinder jacket. By this means a constant and regular flow is maintained. The circulation of the water in the piston and piston-rod is carried on by the following arrangement. The piston-rod, which is of steel, is bored throughout its whole length to a diameter large enough to receive a copper tube *c c* and leave a small annular space around it. This tube is nearly equal in length to the piston-rod, Fig. 335, and is fastened to it at its back end by means of a brass screwed plug, into which penetrates, with easy friction, through the glands of the stuffing box, a pipe *f f*, which is firmly fixed to the cylinder by means of an iron strap *g g*. The water, driven by the pump already mentioned, passes through this pipe into the tube *c c*. Having reached the forward end of this tube, it returns, through the annular space left between it and the piston-rod, as far as the diaphragm *e*, which consists of a brass ring fastened to the piston-rod in the same line as the piston. This diaphragm obliges the water to pass into the piston, and to cool successively its two faces, as shown by the arrows in the section, Fig. 335. The water afterwards escapes through the indiarubber pipe *i*, which is fixed to the back end of the piston-rod. The water is injected into each end of the cylinder by means of two small pipes, Figs. 335 and 336, fixed in the upper part of the cylinder, their ends being closed by a metal disc *l*, and pierced by two inclined holes opening opposite each other, and having a diameter of about one-fiftieth of an inch. The water being forced, under considerable pressure, through these holes by means of the feed-pump, one jet strikes against the other, and is thereby divided into very fine spray. The quantity of water to be introduced by this means is so regulated by experiment as to keep the air completely saturated. Under these conditions, even when the circulation in the interior of the piston is cut off, the temperature of the apparatus will not rise above 25° Centigrade. All the parts, indeed, remain cool with a velocity of sixty-five revolutions per minute, and with the air compressed to six atmospheres. In each end of the cylinder there are two suction valves and one discharge valve, formed of very thin plates of steel with bronze seatings, the valves being kept in contact with the seating by means of spiral springs coiled round the valve stems, Figs. 335 and 337. The dimensions of these valves are as follows: Suction valves, internal diameter of seating, $4\frac{1}{4}$ inches; external diameter of valve, 5 inches. Discharge valves, internal diameter of seating, $3\frac{5}{8}$ inches; external diameter of valve, $4\frac{1}{3}$ inches.

At the Airolo end of the St. Gothard tunnel twelve of these compressors have been erected, in groups of three on one side of a common driving shaft, which is set in motion by four distinct turbines by means of powerful beveled gearing. The coupling boxes or clutches employed allow the isolation of each of these four groups with its motor, while by another mechanical arrangement, which disconnects the beveled gearing, either of the motors may be stopped, the corresponding group of compressors receiving motion from the common driving shaft. These arrangements greatly facilitate the carrying out of repairs, as they allow of any one group of compressors being stopped without its interfering with the working of any other part of the machinery; for even if it be necessary at the same time to repair one of the turbines and a compressor, belonging to different groups, the remaining nine compressors can be driven, as already shown, by means of the common driving shaft. In each group the three compressors *o*, *o′*, *o″*, Fig. 340, are fixed side by

side upon one bed-plate, and connected directly to the three-throw crank-shaft P; this shaft is connected by means of the couplings Q Q′ to the driving shafts R R′, thus producing a continuity between the shafts of each group. On these driving shafts are keyed massive beveled toothed-wheels *s*, which are driven by horizontal turbines T, Fig. 341.

The dimensions of the compressors at Airolo are:

Diameter of piston	18·1 inches.
Stroke of piston	17·7 „
The theoretical volume generated by the compressor at each stroke will be	2·63 cub. ft.
And at each revolution of the shaft	5·27 „
Which will give for each group of three compressors a volume of	15·81 „
At the normal velocity of sixty-five revolutions per minute this will give, for each group of three compressors, a theoretical volume of	1027·65 „
At a pressure of six atmospheres, which is the ordinary working pressure, this quantity will be reduced to	171·27 „
The actual volume, as proved by experience, will not amount to more than 70 per cent. of the theoretical volume, or	119·9 „

This apparatus has been in operation during too short a time to enable us to judge of its merits definitively. Nevertheless, the experience of some months' work at Airolo gives authority for stating that Colladon's compressor, notwithstanding the complication of its parts, and the high velocity at which it is driven, does not require more repairs than the ordinary machines with water columns, which are driven at a much lower velocity; while the amount of its effective work will be fully equal to theirs. It is therefore superior to these latter, as, on account of its greater velocity, it is capable, with a smaller diameter and shorter stroke, and a consequent proportionate reduction in the first cost, of furnishing the same quantity of air at a given pressure. It also possesses the advantage of being able, with a slightly increased velocity, to furnish volumes of air greatly in excess of the normal quantity. This advantage, which is altogether unattainable in a machine with water columns, on account of the great mass of water which has to be put in motion, belongs, however, to all those direct-acting compressors in which the velocity can be increased in proportion as the cooling of the air is more completely carried out. The importance of this advantage can hardly be overrated.

With regard to the complication of its construction, this exists only in the means adopted for carrying on the circulation of the water in the interior of the piston and the piston-rod; and although these means of cooling may be indispensable in those cases in which we are precluded from adopting the more simple, direct, and efficient method of cooling by the water jets, as commonly used for compressing gas, it seems to be proved by the experience at Airolo, where the circulation of the water in the piston has not been maintained, that up to a velocity of sixty-five revolutions a minute, the water jets suffice perfectly for maintaining the temperature within those limits which are favourable to the proper working of the apparatus. If this circulation be abolished, the machine will become one of the most simple, and, on account of its other advantages, the best of all air-compressors.

A series of four sizes of these compressors are manufactured, which it may be well to describe in this place. The compressor itself is, with the exception of its dimensions and some few matters of detail, the same as that which we have just described. It consists of a horizontal double-action cylinder, the piston of which is actuated either by a connecting rod, crank, belt, or toothed gearing, when the power is derived from an independent motor; but when the motor forms a part

of the apparatus, the motor cylinder is placed on the same bed-plate and in a line with the compressor cylinder, and the two piston-rods are coupled together in such a manner as to form but one rod. A fly-wheel connected to the piston-rods by means of a connecting rod and crank, equalizes their motion; while a governor, placed upon a small air-reservoir, into which the water carried over by the air flows, acts in such a manner upon the steam-supply pipe as to cause the velocity of the engine to vary according to the pressure of air which it may be desirable to maintain constant.

The first type A, which is the least powerful, has been designed for the purpose of supplying sufficient air to drive one large size rock drill.

The second type B is sufficiently powerful to drive two of such drills.

Types C and D are formed by coupling two or three of type B, of which any number may be joined, in order to meet the requirements of those works in which a large quantity of air is required. As, however, type B is of itself sufficiently powerful to drive four Dubois-François rock drills, it will generally be found the most useful and economical for employment in mines.

The following table gives the principal dimensions, theoretical and useful effect, power required, and price of each of the four types.

The prices given include bed-plate, connecting rods, cranks, pulleys, and fly-wheels, and a reservoir for the compressed air, in which the latter is deprived of the water previously used to cool it. The prices with engine include, besides the above, an automatic governor which regulates the velocity of the motor according to the pressure of the air in the reservoirs.

			Type A. One Cylinder.	Type B. One Cylinder.	Type C. Two Cylinders coupled.	Type D. Three Cylinders coupled.
Dimensions of the Compressors ..	Diameter of the piston		in. 10·63	in. 15·0	in. 15·0	in. 15·0
	Stroke of the piston		23·26	30·9	30·9	30·9
	Theoretical volume generated per minute at the mean velocity		cub. ft. 181·25	cub. ft. 240·43	cub. ft. 480·86	cub. ft. 721·29
	Revolutions per minute	Mean ..	83	60	60	60
		Minimum	41·5	30	30	30
		Maximum	124·5	90	90	90
	Corresponding velocity of the piston per second	Mean ..	ft. 5·0	ft. 5·0	ft. 5·0	ft. 5·0
		Minimum	2·5	2·5	2·5	2·5
		Maximum	7·5	7·5	7·5	7·5
Power Required ..	Calculated for the different velocities at which the machine may be driven	Mean ..	H.P. 25	H.P. 50	H.P. 100	H.P. 150
		Minimum	12	25	50	75
		Maximum	36	75	150	225
Useful Effect	Volume of air compressed to six atmospheres which the apparatus will furnish per minute, when driven at either velocity	Mean ..	cub. ft. 25·2	cub. ft. 33·6	cub. ft. 67·2	cub. ft. 100·8
		Minimum	12·6	16·8	33·6	50·4
		Maximum	37·8	50·4	100·8	151·2
Price of the Apparatus	Compressors arranged to be driven by an independent motor—steam or hydraulic		£ 290	£ 540	£ 1008	£ 1512
	Combined engine and compressors—the engines being horizontal and non-condensing, with variable expansion		900	1512	2700	4000

As the principal advantage possessed by compressors with direct action, and the one which often causes them to be chosen in preference to all others, lies in their being capable of being

economically worked at velocities varying within wide limits, the above machines have been calculated and designed for a maximum piston speed of 7·5 feet per second; they may, however, be driven at any speed below this, the normal velocity depending upon the volume of air which it is wished to compress per minute. In calculating the effective volumes in the above table, a loss of one-sixth of the theoretical value has been allowed.

Air-Compressors at the Blanzy Collieries.—At the Blanzy mines, where compressed air is employed on a large scale, there has been adopted for its production, in the place of one of Sommeiller's double compressors, which had long been in use, a compressor with direct action, constructed by Revollier, Biétrix, and Co., of St. Etienne, which furnishes 423·8 cubic feet of air per minute, compressed to three atmospheres, whilst the Sommeiller compressor gave but 105·95 cubic feet.

These compressors are composed of two horizontal cylinders, fixed in a line with and upon the same bed-plate as the two steam cylinders, which are fitted with variable expansion on Mayer's system. The piston-rods of the compressors and of the engines are joined by a coupling the pins of which work in guides; the engine piston-rods being attached by means of connecting rods and cranks to the two ends of the shaft carrying the fly-wheel, Figs. 342 and 343. By referring to Figs. 342 and 344 it will be seen that the cooling is produced by a current of water circulating through an external casing or jacket, as well as by the direct injection, at each end of the cylinder, of a jet of water under great pressure through an ajutage or rose pierced with very small holes. The suction and discharge valves are simple cast-iron clacks faced with leather, the seats being also of cast iron.

The principal dimensions of this compressor are as follows:

Diameter of steam cylinder	25·6 inches.
„ compressor cylinder	21·7 „
Stroke of pistons	63·0 „
„ suction valves	59·0 sq. in.
„ discharge valves	47·74 „
Number of revolutions per minute	25 „
Velocity of the pistons per second	4·37 feet.
Theoretical volume generated by the compression piston at each stroke	13·5 cub. ft.
Which gives for each revolution of the two compressors	54·0 „
And for the two compressors, running at a velocity of twenty-five revolutions per minute	1350 „
This reduced to a pressure of three atmospheres will equal a theoretical volume of	450 „
In practice the actual volume will not amount to more than 90 per cent. of the theoretical	405 „

This compressor, which is more simple in its construction than Colladon's machine, may be employed in all cases where an economy in the first cost is not a matter of grave consideration; for though its velocity, which is almost double that of Sommeiller's compressor, combined with its larger size, permits it to furnish three or four times the quantity of air given by the latter, without any increase in its cost, its dimensions and mode of direct action prevent it from being driven at velocities equal to Colladon's compressor; in this latter also, the water jet being more finely divided into spray, the cooling of the air is obtained with a much smaller volume of water, which of itself is equal to an increase in the duty of the machine.

Air-Compressors at the Ronchamp Collieries.—The compressors in use at the Ronchamp collieries, where compressed air is employed upon a large scale, merit attention by reason of the important improvements in the practical details of construction that have been introduced by the manufacturers. The principal advantages claimed for these compressors are: 1. That they occasion no loss by clearance space; 2. That they compress the air to four atmospheres without sensibly raising its

temperature; and 3. That they occupy but little space, and that, moreover, their compactness does not render their parts less accessible for repairs. These repairs, it is stated on the authority of the engineer, amount to a fresh packing for the piston about once a month.

The construction and arrangement of these compressors, which are very simple in their action, will be seen by referring to Figs. 345 to 351. They consist of a horizontal cast-iron cylinder 17·7 inches in diameter, and 39·37 inches long, firmly fixed to a horizontal bed-plate, in which moves the compression piston, which is packed with a leather packing. At each end of this principal cylinder, and communicating freely with it, is another cylinder or vertical column, which, like the first, is partially filled with water. Two gun-metal clack-valves, faced with leather, opening from the outside inwards, and having each a surface of about 15 square inches, serve for the admission of the air; whilst a horizontal valve, placed at the summit of the vertical columns, permits the escape of the compressed air into the conducting pipes and reservoir. The two vertical columns are identical in their construction, and form, with the horizontal cylinder, a double-acting air-compressing engine. The piston-rod is cased with gun-metal, in order to prevent the rapid oxidation of the iron which would take place if it were in contact with the water charged with air at a high pressure. The glands of the stuffing boxes are for the same reason formed of gun-metal.

The volume of air given at each stroke of the piston is in practice 4·9 cubic feet; theoretically, this quantity should be 5·6 cubic feet, thus showing a loss of from 10 to 12 per cent. This apparatus, therefore, theoretically perfect as it is in all parts of its construction, is, practically, far from being so; the loss, however, appears to be due more to the presence of a certain quantity of air, which is held suspended in the water, and which at the moment of opening the suction valves expands, and thus prevents the inrush of the air, than to any loss occasioned by leakage or loss of stroke.

At each stroke of the piston a certain quantity of water is carried over with the air into the reservoir, Fig. 350, which would finally become full if no precautions were taken to prevent it. In order to avoid leaving the conduct of this operation to the care and watchfulness of the workmen, a very simple apparatus is employed. At the bottom of the air-reservoir, the capacity of which is 882·5 cubic feet, is fixed a small copper pipe, which can be closed at pleasure by means of a stop-cock. During the working of the compressors, this cock is slightly opened, so as to allow the water, which is carried into the reservoir with the compressed air, to escape by the pipe into a cistern which receives its water from a common well-pump. The level of the water in this cistern is such that the overflow runs of itself into the tank of the compressors *b b*, Figs. 346 to 348, where its flow is regulated by cocks provided for that purpose. By these means, if there be only a small quantity of water at disposal, it may be made to serve over and over again indefinitely. The only precaution necessary to be taken is, not to open the cock *r*, Fig. 350, before there is some water in the reservoir, and so to arrange the discharge pipe that the compressed air may not escape with the water.

The water in the compressor cylinder being thus constantly renewed, prevents the heating of the air, which otherwise would attain to a very high temperature, a result that would be detrimental to the action and the duty of the machine. When working under ordinary conditions, the temperature of the air-pipes remains sensibly the same as that of the surrounding air, even when the latter is as low as 18° to 20° Centigrade.

As a precaution against the occurrence of accidents, which might occur to the compressors if the

pressure became excessive, a safety-valve S, Fig. 345, is placed upon the pipe through which the air passes to the reservoir, and a counterweight on this valve is so regulated as to allow the valve to rise under a pressure of $4\frac{1}{2}$ atmospheres. This safety-valve is altogether independent of that situate upon the reservoir itself.

Sturgeon's High-speed Compressor.—The chief object sought by Mr. Sturgeon in the design and construction of his high-speed air-compressing engine has been to increase the percentage of the useful effect obtained from the force applied. This object he has endeavoured to attain by the adoption of a new construction of inlet-valves of his own invention, which allows him to run his compressor at high speeds, without danger of these valves becoming unreliable in their action, and without detriment to his machine, allowing for reasonable wear and tear.

The receiver and steam cylinder in this engine are cast in one piece, the air-compressor cylinder being bolted to the receiver on the side opposite to that on which the steam cylinder is placed, as shown in Figs. 352 and 353, in which *a* is the air-compressing cylinder, *c* the steam cylinder, and *b* the receiver. A fly-wheel shaft *d* is carried by two pedestals at the other end of the bed-plate or receiver *b*, and to this shaft are keyed the fly-wheels *e e'*, one at each end; the crank-pins *f f'* on these fly-wheels are fixed at right angles to each other, and are connected in the usual way to the two cylinder pistons. Now, as in the compressing cylinder the pressure is smallest at the beginning of the stroke, and the greater portion of the work is done in the latter part of the stroke, whereas in the steam cylinder the pressure is greatest at the beginning of the stroke, and least at the end, the setting of the crank-pins at right angles to each other enables the steam crank-pin to be in its best position to meet the increasing resistance in a similar ratio. It is said that by this arrangement, and with equal cylinder diameters on both sides, the air-compressor has registered, at one and the same time, double the steam pressure of the other cylinder.

To meet the varying requirements of the air-driven machinery in the supply of air, the following arrangement has been adopted, by means of which the steam engine is enabled to vary its speed automatically, so that when the air-driven machinery is stopped, the air-compressor may likewise stop of its own accord. On the fly-wheel shaft *d* an eccentric *k* is placed, which, by working on to a combination of levers, is made to actuate the valve of the steam engine in such a manner as to lengthen or shorten the travel of the slide, according as the pressure in the receiver falls below or above the required degree, which will necessarily correspond to an increase or slackening of speed. A plunger *q* fits air-tight in a recess made in the receiver *b*, and according as the pressure increases or diminishes, so will the plunger rise or fall, carrying with it in the same direction the fulcrum *o* of a lever *n*, whose centre *o* is accordingly raised or lowered in the guides *p p*. Motion is produced in this lever *n* around its fulcrum *o*, by its upper end being connected with the before-mentioned rod *m*. The valve lever *s*, working from the fixed centre *t*, has a projecting pin *r*, gearing into a corresponding groove cut along the length of the lever *n*, so that the to-and-fro movement of the lever *n* is imparted to the valve lever *s*. From this description it will be evident that the more the centre *o* rises, the more will the travel of the valve be shortened; in other words, the less steam will be admitted into the steam cylinder, whereupon a slackening of speed must ensue, and *vice versâ*. In order to regulate the pressure required in the receiver *b*, a sliding weight *u* is attached to the rod *m*, which, according to the position in which it is set, can be made to maintain the degree of pressure desired in the receiver. When the centre of the lever *n* comes opposite the pin *r* of the lever *s*, the motion of the latter is stopped, and the engine automatically comes to a stand.

In order to reduce the heating of the compression cylinder, it is enveloped by a cavity or tank, which is kept constantly filled with cold water. As this water becomes heated, it is used as feed water for the boiler, and thus a portion of the heat generated, which otherwise proves detrimental, is turned to some advantage. The nicety with which all the working parts of this machine are counterbalanced is evident from the fact, that with a speed of two hundred and twenty revolutions, or 440 feet a minute, no further foundation is required than a few wooden logs placed underneath, to keep the fly-wheels from touching the floor.

The construction of the air-cylinder valves, which form the chief innovation in this type of air-compressor, will be fully understood by a reference to the enlarged section, Fig. 354, and the following description: These valves are fixed in the cylinder covers, and are exactly similar at each end. The inlet-valve *i i* is placed in the centre of the cylinder cover in the form of a circular ring. The cylinder piston is fitted at each end with stuffing boxes *h h*, which are securely packed to the piston, so as to have a frictional hold thereon. The inner end of this stuffing box *h* is made to sit close on the inner surface of the cylinder cover when the two come in contact with each other. Owing to the frictional grip which this stuffing box has upon the piston, as the latter recedes from one end of the cylinder, the corresponding stuffing box becomes drawn in the same direction, till its travel is checked by the stop, shown in the figure, coming against the outside surface of the cylinder cover, when the piston completes the remainder of its stroke independently, while the air is drawn in to the full extent of the stroke. The return of the piston brings the inlet-valve close on to its inner seating, thus preventing the air from escaping out again whilst it is being compressed. To prevent these valves from coming in violent contact on their inner seatings, when working at high speeds, the crank-pins are further so arranged that, at the moment of contact, the respective crank-pin is almost on its centre, or at its lowest speed, and the valve is thus brought gently on its facings, without violent concussion. It is further evident that the opening of such inlet-valves is altogether independent of the vacuum formed in the air-cylinder, inasmuch as they owe their actions to the driven piston. Moreover, the compressed air is here turned to account, in preventing the valve from opening until the piston has travelled sufficiently far to allow time for the delivery valves to close.

The delivery valves *j j*, Figs. 352 and 353, are distributed over the whole inner surface of the cylinder covers, and are in direct communication with the receiver *b*, through the passage *g*. These valves are kept in close contact with their facings, partly by means of a spring thrusting inwards, and partly by means of the back pressure exerted on them by the compressed air in the receiver *b*. As soon as the pressure in the air-cylinders, acting on their inner surfaces, becomes greater than the counter-pressure before mentioned, the springs become compressed, or, in other words, the compressed air in the cylinder forces its way through the valve openings and the clear passage *g*, into the receiver *b*, to be there stored according to requirements. The back pressure on these delivery valves causes them to close again, and the inlet-valves are then ready to open inwards. It will be seen that for the purposes of repairing or cleaning, these delivery valves can be removed without detaching any fast joints.

If we, therefore, compare the present construction with the usual types which have hitherto prevailed we shall find that, notwithstanding the high speed at which the present engines may be run, friction has been reduced by enlarging the delivery areas, and by preventing as much as possible cross currents of air; whereas usually these effects have been increased by the introduction of high speeds.

Air-Receivers.—As machines driven by compressed air in underground workings do not run continuously, the consumption of air is irregular; consequently it becomes necessary to store the air as it is received from the compression cylinders, in a reservoir of sufficient capacity to annul the effects of the irregularity existing between the production and the consumption. The minimum capacity of this reservoir should be twenty times the average consumption a minute, when only one compressor is employed; ten times when the compressors are two in number; and five times when there are three compressors. The form of the receiver or reservoir is a matter of small importance. Frequently an old boiler is used for this purpose. At the Sarrebruck mines the receiver consists of three old boilers communicating one with another. Two of these boilers are placed side by side, and the third is placed upon and between them, resting equally upon each. Every receiver should be provided with a pressure gauge, in order that the pressure of the contained air may be readily ascertained at any moment. The outlet from the receiver should be provided with a cock, for the purpose of cutting off communication between it and the conduit pipes. There should also be a discharge cock at the bottom of the receiver, for the purpose of removing the water which is carried in by the air, and which accumulates at the bottom. A neat and effective means of discharging the water has already been described in connection with the Ronchamp compressors. It is hardly necessary to remark that the receiver should occupy a situation in which it will not be liable to be exposed to heat, the action of which upon the contained air would occasion a loss of work.

Air-Conduits.—For the conveyance of compressed air from the reservoir to the points at which the machines are required, both cast-iron and wrought-iron pipes are used. When cast iron is the material employed, the pipes are cast with a flange, and the joint is made by means of an indiarubber washer inserted between the flanges. In some cases, one flange is provided with a groove, and the other with a corresponding annular prominence, the edges both of this projection and of the groove being beveled. To form the projection, the flange is turned down, and the groove is also cut in the lathe. The ring of indiarubber is placed in this groove, which is $\frac{1}{2}$ inch broad and $\frac{1}{4}$ inch deep.

Wrought-iron tubing is in many cases preferable, especially on account of its lighter weight. This tubing is usually manufactured in 14 feet lengths, and with an internal diameter of $3\frac{1}{4}$ inches. Such a length will weigh about 80 lb. The joints in this case are made by means of flanges $7\frac{1}{2}$ inches in diameter, strongly brazed upon the ends of the tube, and pierced with four bolt-holes $\frac{3}{4}$ inch in diameter. In order to obtain the requisite degree of rigidity, great care is needed in putting on these flanges. Before applying them a groove is cut in the lathe in the thickness of the flange, and a copper ring of $\frac{5}{32}$ inch on the side inserted. This ring is, by the process of soldering, rendered solid with the flange and tube, and by that means a perfectly air-tight joint is made. In joining the tubes, an indiarubber washer is inserted between the flanges.

In certain situations, where rapid oxidation of the metal is likely to occur, an air-conduit may be composed of both cast and wrought iron pipes, each material being confined to the locality for which its qualities render it the more suitable. All air-pipes should, previously to their being put into use, be tested by hydraulic pressure up to ten atmospheres, and also by air pressure under water up to seven or eight atmospheres. By such means any latent defects in them are rendered apparent, and confidence in their resisting and retaining powers is created.

When a considerable length of air-piping is laid down, means must be provided to allow of expansion and contraction under the influence of changes of temperature. In underground workings, the temperature is sufficiently constant to justify a neglect of such precautions; though even there it

is well to be prepared against a sudden rise of the temperature. But in the shaft and at surface the conditions are different, and rollers and compensating joints become a necessity. A form of compensating joint that has been proved to act satisfactorily in practice is shown in Figs. 355 and 356. It consists of a tube of copper, of the same dimensions as the iron tubes, and bent into the form shown in the drawing. The flanges of this tube are applied in the same manner as those of the iron tubes. In practice it has been found necessary and sufficient to insert one of these compensating joints at intervals of about 100 yards.

The tubing used to connect the machine drills with the fixed iron tubing is always flexible. The material used is indiarubber, and great thickness is given to the tubing to ensure strength. As a protection from injury caused by friction against the rough surfaces of the rock, such tubing is covered with coarse canvas. The internal diameter of the largest size used is 2 inches, and that of the smallest about $\frac{3}{4}$ inch.

Water Reservoirs.—In rock boring by machinery the application of water greatly facilitates the operation, by keeping the bottom of the hole free from the débris, and hence it is highly conducive to rapidity of execution. It has been proved by experience that the rate of boring in a dry and in a wet hole varies as 1 : 1·5; that is, it takes one and a half times as long to bore a hole dry, as to bore a hole with the assistance of water. Thus it is possible to reduce the time of boring by one third. Moreover, the great heating produced in the borer bit by the blows upon hard rock causes a rapid deterioration of the tool, and hence it becomes necessary to change and to repair it more frequently. Another great objection to dry boring is the production of a large quantity of fine dust, which is a cause of annoyance to the workmen, and of destruction to the packing and the rubbing surfaces of the machinery. For these reasons a supply of water is desirable; and when the holes are inclined upwards, it becomes necessary to inject the water into them with considerable force. For this purpose water reservoirs are used. These reservoirs are constructed of galvanized iron, and are made of various dimensions, according to the conditions under which they will have to be used. They are filled through a funnel-cock, which being closed renders them air-tight. By means of a piece of tubing, the water reservoir may be placed in communication with the air-pipe, from which the requisite pressure is obtained; the water is directed into the bore-hole as a strong jet by means of another piece of flexible tubing provided with a suitable nozzle. When a heavy drill support is employed, capable of running upon tramways, the water reservoir may be conveniently fixed upon the support. But in other cases there is a difficulty in using a reservoir so as not to be an encumbrance rather than a means to rapid progress.

Reserve Machines and Tools.—In order to avoid the costly delays which might be occasioned by the derangement of the machine drills, there should always be machines in reserve for all important undertakings. The number of the latter required will obviously depend upon their liability to get out of order. When machines of the simplest construction and of good workmanship are employed, one in ten will be sufficient under ordinary conditions of work.

Also it is highly desirable, to avoid frequent delays, to have at hand a store of the pieces which are most subject to wear and derangement, such as bolts, nuts, unions, packing leathers, flexible tubing of various diameters, and any other parts that are known to require frequent replacing. And besides these, there should be always ready at hand the tools necessary for replacing the parts, and for making any slight alteration in their dimensions which may be required. If such means be provided, the delays incidental to the employment of machinery will be reduced to a minimum.

EXPLOSIVE COMPOUNDS FOR MINING PURPOSES.—In the foregoing sections, we have considered the means of perforating rock, for the purpose of placing in a favourable position a charge of explosive compound. It now remains to consider these compounds themselves, and to show the importance of possessing a complete and an accurate knowledge of their properties before attempting to apply them to use. Such knowledge is all the more necessary as there is great danger in dealing with a substance of the character in question, of whose particular nature we are wholly or even partially ignorant.

An explosive compound is a mixture of substances capable of being suddenly transformed into gases by the application of heat. Hence an explosion is a sudden evolution of gases; and as these gases occupy a much larger volume than the original substances from which they were evolved, pressure will be produced upon the body in which they are retained. It is obvious that the degree of pressure, which represents the strength of the explosive, will vary as the volume of the gases evolved, and thus we have a means of measuring and comparing the strength of the various compounds. Gunpowder being taken as the standard of measurement, and the volume of its gases being assumed as one for a unit of weight of the substance, the volume of gases evolved by the same weight of some other substance, will represent its strength relatively to that of gunpowder. In this way, other things being equal, the value of an explosive may be ascertained when its chemical composition is known.

The effect of an explosive, however, does not depend wholly upon the volume of gases evolved. The rapidity of their evolution modifies the effects produced in no inconsiderable degree. When a substance in a confined space is slowly converted into gas, this gas will make its escape in the direction in which the least resistance is opposed, and the pressure upon the containing body can in no part be greater than that which is exerted upon the part which yields; that is, it can never be greater than the resistance of the least resistant part. When, however, the gas is instantaneously evolved, the whole force which it is capable of developing is exerted upon every part of the containing body, because motion requires time, and as no time is allowed for the less resistant parts to yield by moving away before the pressure of the fluid, it follows that the whole force of the latter must be exerted upon all alike. Absolute instantaneity is never obtained in any explosive, but the action of some is so exceedingly rapid as to be practically instantaneous. Thus in measuring the strength of any explosive compound, two things have to be taken into consideration: the *relative volume* of the gases evolved, and the *rapidity* with which the evolution takes place.

The question of rapidity in the evolution of gases by an explosive is one of great practical importance, inasmuch as the *effects* produced are, as previously stated, very different with different velocities. When the transformation of a substance into its gaseous form is slow, the gases of a charge in a bore-hole do not exert their full energy at once, but they force their way gradually up the hole, and thereby bring their greatest pressure to bear at a considerable distance from the bottom. This is the reason why slow explosives, as gunpowder, do not blow the rock out to the full depth of the hole. Moreover, as time is allowed to elapse during the progress of the explosion, the retaining body, that is, in the case we have assumed, the rock, yields along the line of least resistance, and directly along that line only. The result is that the rock is *lifted* out bodily, or, as miners and quarrymen express it, "the explosion heaves." When, on the contrary, the transformation of the substance occurs instantaneously, the full force of the enlarged volume is at once exerted in all directions, and the rock is not only blown out to the full depth of the hole, but, being violently strained in every direction, it is blown out in fragments, or, in miner's language, "the explosion

shatters." Thus, classified according to their action, we have two kinds of explosive compounds, which may be described as "rending" and "shattering" compounds respectively. These classes of explosives are represented by gunpowder and nitroglycerine; the other compounds will be ranged under one or the other of these classes, according as their properties approach more nearly gunpowder on the one hand, or nitroglycerine on the other.

It will appear from the foregoing statements that the strength of an explosive compound, or in terms more strictly accurate, its available strength, depends upon two conditions, namely, the relative volume of the gases evolved and the rapidity of the action of evolution; for it has been shown, that the full force of the expansion cannot be exerted upon the containing body, except when the evolution of the gases takes place instantaneously. Hence it follows that with equal relative volumes of gases, the shattering compounds possess greater available strength than the rending compounds, and that, with this condition, the available strength of any compound is as the rapidity of evolution. When, therefore, we know the relative volume of the gases generated by any explosive, and the rapidity with which they are produced relatively to the case of gunpowder, its strength relatively to the latter compound may be accurately determined and clearly expressed.

The advantages of strength in an explosive compound are sufficiently obvious to need but little explanation. If, weight for weight, one of two compounds which may be purchased at the same price possesses greater strength than the other, there will evidently result an economy from the adoption of the stronger, since a smaller quantity will be required. But the economy is to be sought mainly in another direction, and it may exist in an important degree even when there is great inequality in the price of the two substances. To produce a determinate effect by means of a blast, whatever the nature of the explosive adopted may be, the centre of action of the charge must be placed at a certain point relatively to the unsupported faces of the rock. The greater the strength of a given volume of the explosive, the smaller will be the space occupied by the charge; that is, the space varies inversely as the strength of the explosive. Hence the section of the bore-hole may be varied in the same ratio while keeping the centre of action at the same points; and by this means the labour of boring may be greatly lessened. For as the area of a hole increases as the square of the diameter, it follows that a small reduction of the latter will materially diminish the cube of the rock to be removed by the boring tool. A limit is, however, placed in this direction by the strength of the tool, the dimensions of which cannot in practice be indefinitely reduced. But in the case of a very small diameter of bore-hole being required theoretically, the condition may be in some degree satisfied by diminishing the depth. So that generally it may be stated that the labour of boring will vary as the strength of the explosive employed.

Another advantage of the strength due to rapid ignition lies in the nature of the "tamping" required. When the evolution of the gases takes place slowly their force is developed progressively, and in order to restrain this force until it has become sufficient to rend the rock, it is necessary to "tamp" the hole, that is, to fill it above the charge with some strongly resistant substance. This necessity involves considerable labour, and some danger. But when, on the contrary, the evolution occurs instantaneously, any resistance will prevent the gases from escaping through the bore-hole, and therefore the atmosphere alone will be sufficient in many cases, and a very light tamping in all. Thus we have, besides a lessening of the danger, an important economy resulting in this direction from the employment of shattering compounds. The advantage of an effective action without tamping becomes especially apparent when blasting in fissured and vughy rock. In such a case, it is often impossible to bore a hole that is not in communication either with the face or with

deep fissures or spacious vughs in the rock; and under such conditions as these, a slow explosive would exhaust its energy through these spaces.

It will be justly inferred from the foregoing statements, that the shattering compounds are generally more suitable for blasting purposes than those which are of a rending character. But as circumstances in all cases modify the means employed, so in blasting operations conditions will often occur that will be best satisfied by the latter class of explosives. Thus in dealing with tender and friable rocks the shattering compounds would produce but little effect, inasmuch as such material would be simply crushed within a certain radius of the charge. In general it may be stated that the less hard and tenacious the rock, the less suitable the shattering explosives become. So also the purpose of the blasting will determine the class of explosives to be employed. In building-stone and slate quarries, or in a coal seam, where it is required to extract the produce in a certain condition, the rending class is alone applicable. In such cases, the shattering explosives would render a large proportion of the produce useless by breaking it up into small fragments. On the other hand, for the extraction of the substances in large and sound blocks, the lifting and rending action of the slow explosives is particularly suitable. But in ordinary limestone and road-metal quarries, in tunnels, headings, and shafts, and in many metalliferous veins, where the state in which the produce is extracted is of little or no importance, the strong, shattering explosives may, if no other conditions weigh, be advantageously employed.

Hitherto we have considered explosive compounds solely from the point of view of their efficiency as blasting agents. There are other conditions, however, to be taken into account in determining the suitability of a given compound for any particular purpose. In many situations, but more especially in shafts, there is an abundance of water present. If the nature of the explosive to be used is such as to be readily affected by water, precautions must be taken to protect it from the influence of the water. These precautions, the character of which has been already described, necessitate much labour and expense. Moreover, the difficulties of tamping in such situations are enormously increased. Hence a compound whose properties undergo no change in the presence of water will, under the conditions supposed, offer advantages of a weighty character. And if, besides this, it be of the class for which water will serve as a sufficient tamping, another advantage will be added of hardly less magnitude. In subaqueous blasting operations, these qualities of the compound will obviously assume their highest degree of importance.

There yet remain other considerations respecting the nature and action of an explosive that are of the highest moment. All the merits to which attention has been directed may exist in a compound side by side with defects of a character that will render its employment impracticable. The gases evolved by an explosion are always of a more or less unwholesome nature; but when they become particularly noxious, the compound becomes unfit for use in confined situations. This circumstance is of weighty importance in mining operations which are carried on in close shafts, or still closer headings. Under such conditions, an explosive that generates a large volume of noxious fumes is altogether unsuitable, and its use, whatever merits it may otherwise possess, ought to be prohibited. Safety in handling is also an essential quality in an explosive. Compounds in which an explosion may be produced by unknown causes, or by causes that can be ill provided against, introduce an element of danger that cannot be compensated by any merits which they may possess. This is a question that bears heavily upon the responsibility of those who have the conduct of operations, and such should be on their guard, particularly in these times of hasty execution of work, lest a desire to

keep pace with the requirements of the times should tempt them to adopt a more dangerous compound, to the risk of human life.

There is yet another condition which an explosive compound must satisfy to enable it to be of common use, namely, cheapness of production. The exigencies of rock blasting are such as require large quantities of the substance employed, and unless that substance can be obtained at a cheap rate, the cost of excavating by such means will not bear a favourable comparison with that of purely hand labour; or, where the latter is impracticable, it will render the enterprise unprofitable. This condition reduces a numerous list of explosive substances to the following few, which alone are extensively applied to blasting purposes.

In the foregoing considerations it has been assumed that the strength of an explosive is dependent upon two conditions, namely, the relative volume of the gases generated, and the rapidity of their evolution. This view supposes the relative volume of the gases to be that existing at the moment of explosion. But as the volume at that moment is dependent upon several causes, it will be well to separate the latter, in order to obtain thereby a fuller and more accurate view of the subject. If, then, we understand relative volume to mean that of the gases when at the same temperature as the substance from which they were evolved, the strength of an explosive will obviously depend upon: 1. The *relative volume* of the gases generated, to which the force developed is primarily due; 2. The *density* of the gases, whereby the degree of their expansibility is limited; 3. The *heat* generated by the chemical change produced in the substance, which heat causes the gases to expand in volume according to a law already explained; and 4. The rapidity with which the chemical change in the substance takes place. The volume and the density may be expressed by the *weight* of the gases, an expression of more convenient use. The relation subsisting between the weight of the gases produced, their nature, and the heat generated by their production, is a complex one, the three being mutually dependent. If, however, the foregoing remarks concerning these matters have been fully understood, there should be no difficulty in perceiving this relation, nor in applying the practical consequences that result from it. In treating of the combustion of coal, the production of carbonic oxide and of carbonic acid was considered, and it was shown that the heat generated in the latter case was double that generated in the former case. Also in treating the subject of compressed air, it was demonstrated that the volume of any gas is dependent upon its temperature. When these facts are borne in mind, the effects of perfect combustion in the explosive compound, and the importance of the degree of heat attained in modifying the expansion of the gases evolved, become clearly apparent; and we are enabled thereby to form at least an approximate estimate of the force which any given explosive of known composition is capable of developing. By reason of the difficulty of taking every condition into account, the relation of the strength of an explosive to the volume of its gases, and to the heat generated, has not been determined experimentally with precision. But the researches of Messrs. Roux and Sarrau have shown conclusively that the simple explosive force of a substance is proportional to the product of the weight of the gases evolved by the heat generated; and that the detonating force is proportional to the heat. The difference between simple explosion and detonation will be hereafter explained.

Gunpowder.—Gunpowder is the representative of the rending class of explosives, and it is the only one of that class that is extensively employed. It is a compound of sulphur, saltpetre, and charcoal, and exists in a form that is too well known to need description. Until very recent times,

this explosive was the only one applied to blasting purposes. Its slow-burning character renders it admirably suitable for those operations in which a rending action is required. Indeed, in the cases to which allusion has already been made, namely, those of building-stone and slate quarries, and seams of coal, gunpowder is alone admissible. And for these purposes this compound will probably continue to be employed, whatever the modifications introduced into those of the other class may be, since it is difficult to conceive of an explosive more suitable in its mode of action, or capable of being more cheaply produced. But in the cases in which a rending action is not desirable, gunpowder, except under certain conditions to be explained hereafter, is greatly inferior to the compounds of the other class, and its use in such circumstances is being gradually abandoned. Besides the unsuitability which is due to its slow action, gunpowder also possesses the defect, very important for blasting purposes, of being readily affected by moisture. This property renders it difficult of employment in wet ground. By the adoption, however, of fitting precautions, such as the use of waterproof cartridges, and the other means that have been already described, the defect may be overcome, though at the cost of labour and an increased outlay. One immense advantage possessed by gunpowder is the safety with which it may be handled and transported from place to place. This advantage is not unfrequently contested by those who are prejudiced in favour of the newly-introduced shattering explosives; but the experience of centuries is sufficient to place this quality of gunpowder beyond reasonable dispute.

The eminent gunpowder makers, the Messrs. Curtis and Harvey, stimulated by the success which has attended the introduction of the nitroglycerine compounds, have lately made an attempt to render their explosive capable of competing with those compounds in the very cases to which the latter are most applicable, namely, to those operations in which a shattering action is desirable. In this attempt they have succeeded in a very remarkable degree. The new compound which they have produced possesses a strength greatly superior to that of the ordinary blasting powder. This increase of strength appears to be due rather to a quickening of the ignition than to an augmentation of the relative volume of the gases evolved. If it can be shown that the velocity of the gases during evolution is capable, in the case of gunpowder, of being notably increased by a change of the chemical composition, much will have been accomplished towards the reintroduction of that safe, convenient, and cheap explosive into those situations from which it has been driven by the nitroglycerine and nitrocotton compounds. This result, in some degree at least, appears to have been attained by the Messrs. Curtis and Harvey, in their new blasting powder, and it must be acknowledged that in this they have done good service to mining. We shall have occasion later, when treating of the most effective means of firing explosives, to show how this new compound may be made to equal in disruptive force the best preparations of dynamite. It may be desirable to add that the manufacturers claim for this compound, which is commercially known as the E.S.M. powder, a strength equal to five times that of the common blasting powder. Such a degree of strength may be undoubtedly attained under the condition of suitable firing to which we have alluded. If this fact be viewed relatively to the foregoing considerations on the advantages of strength, it will be evident that the use of this powder must lead to a notable economy.

Gunpowder is sometimes employed in a compressed form in cartridges for blasting purposes. The chief object of the compression is to obtain within a minimum volume a given store of force. This object, however, is only partially attained when the firing takes place by the ordinary means, inasmuch as the combustion of the compressed grains proceeds slowly, thereby causing a waste of

energy. But when special means of firing are adopted, a marked economy is to be gained by compression. This question will be considered in a subsequent section.

Nitroglycerine.—Nitroglycerine is the representative of the " shattering " class of explosive compounds. This violent explosive was first discovered by Sobrero in 1847, but it was not till the year 1860 that it was applied to blasting purposes. Since that time, when it was brought prominently into notice by Alfred Nobel, a Swedish engineer, its use, under various forms, has been rapidly extending.

Nitroglycerine, or glonoin, exists in its pure state as a nearly colourless liquid; but usually, owing to the colouring matters contained in the glycerine employed in its manufacture, it is of a light yellow colour, somewhat oleaginous, inodorous, and of a sweetish pungent flavour. When applied to the tongue, in the most minute quantity possible, the maxillary glands are stimulated, and in a few minutes a violent throbbing headache supervenes. The latter effect is produced by merely touching it with the hands. It has been remarked, however, that the system speedily becomes sufficiently accustomed to the poisonous nature of this compound to allow of its being handled with impunity. The specific gravity of nitroglycerine is 1·6 at a temperature of 60° Fahr. It solidifies at 45° Fahr. if perfectly pure; at 320° Fahr. it decomposes, giving out red vapours, and at a higher temperature it explodes. It is insoluble in water, but soluble in alcohol—one part to four parts,—ether, and some other organic products; it separates from the alcoholic solution by the addition of water. When in a pure state, nitroglycerine remains for a long time unchanged, even when exposed to the varying influences of the weather; but if impure, it is subject to rapid change, becoming of an orange-yellow colour, and evolving fumes. When in this state, it does not congeal till a much lower temperature than 45° Fahr. has been reached, and it very readily explodes. Most of the terrible accidents that have occurred from the accidental explosion of nitroglycerine have been due to this change of state.

Nitroglycerine is produced by the action of nitric acid in the cold upon glycerine, the sweet substance obtained from oils and fats by the process known as saponification, that is, a treatment of these fatty substances with an alkali, or with water itself at a high temperature, or with steam. The compound may be safely prepared, according to Professor Abel, by adding concentrated glycerine gradually to a cold mixture of one part of nitric acid, of specific gravity 1·52, and three parts of concentrated sulphuric acid, the mixture being kept cold by artificial means. When the proper proportion of glycerine has been introduced, the mixture being stirred during the addition, the latter is poured into water, by which the separation of the nitroglycerine is effected. Nitroglycerine is manufactured as three different preparations, due to differences of chemical composition; these preparations are known respectively as "Mono-nitroglycerine," "Di-nitroglycerine," and "Tri-nitroglycerine." The latter has shown itself to be the most suitable for industrial purposes. The most important matter, however, in the manufacture of nitroglycerine is the purity of the materials employed. The glycerine must be free from sugar, fatty acid, or saline impurities; and the acids required must be used in the due proportions, there being no more water therein, nor in the glycerine, at one time of making than another. It is essential that the resulting compound be of uniform quality, invariable in composition, and free from water, and all other impurities. If these conditions of manufacture be not fully satisfied, the substance becomes a dangerous one to handle by reason of the changes which it is liable to undergo. The impure compounds may be recognized by their deep yellow colour, and also by the low temperature required to congeal them. If all such were rejected

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by the persons in charge of blasting operations, the number of accidents from premature explosions would be greatly reduced.

A description of the mode of manufacturing nitroglycerine would be out of place here; we shall, therefore, give only the formulæ according to which the three several preparations may be produced. These formulæ, which are due to Liecke, are the following:

Mono-Nitroglycerine.—Glycerine, 100 grammes; nitric acid, sp. gr. 1·3, 200 grammes. Dissolve the glycerine in the nitric acid, and add sulphuric acid 200 cubic centimetres. The product should be $\left.\begin{matrix} C^3H^5O^2H \\ NO^4H \end{matrix}\right\} O^4$.

Di-Nitroglycerine.—Sulphuric acid containing 1 eq. water, two volumes; nitric acid, sp. gr. 1·4, one volume; mix the foregoing, reduce the temperature to 32° Fahr., or below, and drop into it: Glycerine, pure, one volume. The product should be $\left.\begin{matrix} C^3H^5O^2H \\ 2NO^4H \end{matrix}\right\} O^4$.

Tri-Nitroglycerine.—Sulphuric acid, 3·5 parts; nitrate of potash, 1 part; cooled to 0° Fahr. This produces $KO + 4SO^3 + 6HO$; from this the concentrated fuming nitric acid is separated by decantation. Being maintained at the temperature of 0° Fahr., glycerine 0·8 part is very gradually added, giving the product $\left.\begin{matrix} C^3H^5O^2NO^4 \\ 2NO^4 \end{matrix}\right\} O^4$.

In combining the glycerine with the acids, a large amount of heat is evolved, and means must be provided for absorbing this heat, so that the mixture shall not under any circumstances exceed a certain temperature. This temperature Sobrero fixes at 32° Fahr. If this condition be not fulfilled, the character of the resulting compound is changed, and may become unsafe for use. From the foregoing remarks concerning the manufacture of nitroglycerine, it appears that safety in handling the compound is, in a high degree, dependent upon the purity of its constituents, and the care exercised in combining them.

As a blasting agent, nitroglycerine possesses merits which render it greatly superior to gunpowder for many purposes, in company with some grave defects. When ignited in the open air, it burns away rapidly, but does not explode. When confined, however, it explodes, when ignited, with great force. In both cases very little smoke is produced; and, if the combustion is complete, the resulting gases consist of nitrogen, carbonic acid, and vapour of water. Thus, in confined situations, the fumes produced by an explosion of nitroglycerine are less noxious than those resulting from an explosion of gunpowder. But if the combustion is incomplete, large volumes of carbonic oxide are evolved, and in such a case the products are of a particularly noxious character. Hence it is important, when employing nitroglycerine and its compounds, so to fire the charge that the combustion of the substance may be complete. A sharp blow will provoke an explosion in nitroglycerine, and the same result may be produced by the detonation of a charge of fulminate in contact with it. When fired in this way, nitroglycerine explodes with extreme violence, and when applied under such conditions to blasting operations, effects are produced that could not be obtained by the use of gunpowder. The enormous force developed by this explosive when fired by detonation allows deep holes of small diameter to be adopted, a consequence that leads to a considerable economy of labour, and to a notable acceleration of the progress of the work. Any explosive compound, even in minute quantities, is capable of producing an explosion of nitroglycerine, and this circumstance renders the latter dangerous for common use. The insolubility of nitroglycerine in water gives it a very great advantage over gunpowder by allowing of its use in wet situations, or under water, without any protective

covering. As this property, moreover, renders water tamping sufficient, it must be considered as constituting one of its greatest merits. Though nitroglycerine may be very readily exploded when in a liquid state, when frozen it can hardly be exploded by the strongest detonators, particularly when of pure composition. This property constitutes both a merit and a defect; a merit inasmuch as the compound may be safely transported in a frozen state, a defect as it freezes at a high temperature. The latter property is highly conducive to convenience in transport, but it is a somewhat serious disadvantage when the substance has to be applied in use.

The chief defect of nitroglycerine, however, when employed in its pure state as a blasting agent, is due to its liquid form, and its consequent tendency to leak out of receptacles in which it is transported, stored, or used. In blasting operations, the explosive material with which the hole is charged may flow into fissures in the rock, and thus be conveyed to points where its existence would not be suspected. Afterwards, by the boring of other holes at these points, an accidental explosion may be caused attended with disastrous consequences. Numerous terrible nitroglycerine explosions have occurred in different parts of the world, the majority of which are considered to have been primarily due to the leakage of the substance from the packages in which it was stored and transported, notwithstanding the care exercised in the construction and the filling of these packages. The great susceptibility of nitroglycerine in the liquid form to detonation, especially during hot weather or in tropical climates, would lead to the explosion of portions of the liquid which had escaped from the packages, by accidental concussion, or comparatively light blows.

Dynamite.—The inconvenient and dangerous character of nitroglycerine in its liquid form led to the abandonment of its use, and, in numerous instances, to the prohibition of its manufacture. To overcome the difficulties thus occasioned, Alfred Nobel, to whom the introduction of the compound as an industrial agent was due, commenced a series of observations and experiments which ended in the very important discovery that the readiness with which an explosion may be produced in nitroglycerine by means of a detonation is not lessened, but rather increased, by the presence of an inert substance. Nobel recognized at once the immense importance of this discovery, since it afforded a means of removing the principal defects possessed by the liquid nitroglycerine. By mixing the latter substance with a material of a porous character, its form would be practically changed to that of a solid, in which condition it might be handled like any other solid explosive substance, while affording the additional advantage of plasticity. It was clear, indeed, that if nitroglycerine could be presented in this way, all the objections arising out of its liquid form would be completely removed. As it was obvious that the strength of the resulting compound of explosive and inert matters must necessarily be less than that of the pure substance, in proportion to the quantity of inert matter present, it became desirable that the latter should be very porous, so as to absorb as much of the explosive liquid as possible. It was also important that this inert matter should be of a nature incapable of giving rise to chemical change in the nitroglycerine itself. These properties were found combined, and in a high degree of perfection, in a kind of silicious earth, abundant in many parts of Germany, where it is known as "kieselguhr." This earth, or "rotten-stone," was therefore selected as a suitable absorbent medium, and it was found by experiment to fulfil all the conditions required in a very complete manner. The solid compound resulting from the mixture of the liquid nitroglycerine with this infusorial earth was called by Nobel *dynamite*, under which name it has since come into common use. Dynamite contains about 75 per cent. of nitroglycerine; but as the strength of the latter is so much greater than that of gunpowder, this degree of dilution does not occasion any

important detriment to its usefulness. It may, moreover, be remarked here that though the *strength* of dynamite is only 75 per cent. of that of nitroglycerine, regarded from the point of view of the *effects* which it is capable of producing, it is scarcely inferior to the latter, by reason of the forces developed by its explosion being more widely distributed.

Dynamite, thus constituted, is a moist pasty substance of a light-brown or pinkish-yellow colour. The only defect to be feared was the exudation of the liquid nitroglycerine from the mass. But experience has proved that the kieselguhr is capable of absorbing and retaining, even under considerable pressure, the proportion of nitroglycerine already mentioned. Improvements in the mode of preparation have removed any tendency that might have existed towards this source of danger. Dynamite is now supplied in the form of small cylindrical cartridges, consisting of the explosive in a compact condition, enclosed in a wrapping of parchment paper. These cartridges are consolidated by pressure, whereby any excess of the liquid, which the porous earth will not hold absorbed, is expelled. Thus the separation of the nitroglycerine during transport, handling, or exposure to elevated temperatures, appears to have been effectually guarded against. The consistency of the dynamite charges prepared in this way is that of moderately dry putty, and the fingers are scarcely soiled with nitroglycerine when the uncovered substance is handled.

The plastic character of dynamite constitutes an important advantage in practice, inasmuch as the charge may be made, by pressure, to fill the bore-hole completely, a condition that is essential to the full utilization of the gases evolved by an explosion. This advantage becomes particularly apparent in rugged and uneven holes.

The explosion of dynamite takes place under precisely the same conditions as that of liquid nitroglycerine. When in a frozen state it explodes with difficulty; no explosion can be started in it when its temperature is below 32° Fahr. If fired by the ordinary means when exposed to the air, it burns slowly, after the manner of moistened or compressed gunpowder, with a characteristic yellow flame. The products of this combustion are nitrogen, carbonic acid, and vapour of water, accompanied with traces of nitrous vapours sensible to the smell. If combustion is incomplete, carbonic oxide is produced. The silica remains as a fixed residue. When dynamite is fired in a confined situation, it explodes violently, provided the containing body offers great resistance. Otherwise, no explosion occurs. Thus a strong wooden cask, bound with iron hoops, and containing 11 lb. of dynamite, was on one occasion placed upon a fire and there consumed. At a certain moment the cask burst slowly, and the contents burned as in the open air. The same results were obtained when a thin sheet-iron cask was substituted for the wooden one. The direct ignition of dynamite in confined situations is difficult, and can be satisfactorily accomplished only by means of a strongly detonating priming charge. When fired in this way, whether in a confined situation, or in the open air, dynamite explodes with great violence. If struck with a hammer upon an anvil, the portion struck explodes violently, but unless the blow is very heavy and the resulting detonation severe, the explosion is not communicated to the rest of the mass. The shock of stone upon stone will seldom provoke an explosion in dynamite, and the shock of iron upon wood, or of wood upon stone, has never been known to produce that effect.

Lithofracteur.—Numerous attempts have been made to substitute combustible and explosive absorbent media for the incombustible silicious earth used in the preparation of dynamite. The purpose of this substitution is to increase the strength of the explosive by rendering the absorbent matters, which in dynamite are wholly inert, themselves explosive, to ensure perfect combustion when

the charge is fired, and to prevent the formation of noxious gases. The first of these objects is unattainable in the direction in which it is usually sought. No two explosive substances generate their gases with the same degree of rapidity, and it is obvious that if any two be mixed as independent explosives, the resulting compound cannot exceed in strength that of the more rapid substance, since the tardy forces of the other can take no part in the work done. The strength, however, of a compound may be greater than that of either of its explosive constituents when the latter are chosen to act in conjunction in *producing* an explosion; in other words, if the several ingredients are of such a nature and in such proportions that they are capable of acting towards each other in a manner that tends to promote rapid and perfect combustion. This condition has been overlooked in many of the nitroglycerine compounds that have been introduced as improvements upon dynamite. Many of these compounds having failed to evince the superiority claimed for them, while they unmistakably showed themselves to be more dangerous to handle, have never got beyond the experimental stage. Others, having proved in some degree successful by reason of the favourable conditions under which they were brought into notice, are slowly but surely dropping out of use. Among these unsuccessful attempts, however, others of a different character were made. These, based upon a true chemical knowledge, have, in a more or less satisfactory degree, attained the end proposed; and are likely to assume, in the future, an importance which is not yet accorded to them. These compounds we now purpose to describe.

Lithofracteur, by reason of its extensive application as a blasting agent, possesses a claim to first notice. It consists, according to Lieutenant Trauzl, of about 52 per cent. of nitroglycerine, 30 per cent. of silicious earth and sand, 12 per cent. of powdered coal, 4 per cent. of nitrate of potash, and 2 per cent. of sulphur. These proportions, however, are not always adopted, and frequently an impure kind of gunpowder and sawdust are employed as ingredients. The nitroglycerine is prepared with special regard to purity, and to this circumstance is probably due the immunity from accident which has hitherto marked its manufacture. Thus constituted, lithofracteur presents itself in the form of a dark, blackish-grey, pasty substance. It is made up into cartridges in the same manner as dynamite, and may be used in precisely the same way, and under precisely the same conditions. In the matter of exploding, there is no difference observable between lithofracteur and dynamite. It is claimed for the former substance that, containing only 50 per cent. of nitroglycerine, it is capable of developing a force equal to that of dynamite containing 75 per cent., and consequently is cheaper than the latter compound; and that its combustion produces fumes of a less noxious nature.

Horsley's Powder.—Numerous attempts have been made to substitute chlorate of potash compounds for gunpowder, which compounds are capable of more violent action than the latter. But most of these attempts ended in failure, by reason chiefly of the dangerous character of the compound. The property, which they all possessed, of exploding when subjected to comparatively slight friction or percussion, would alone have sufficed to prevent their being adopted as practically useful explosive agents, even if a decided superiority over gunpowder in the matters of efficiency and economy had been shown. To lessen this tendency of the chlorate of potash mixtures to explode prematurely, inert substances were added for the purpose of serving as protective agents by absorbing the violence of the blows or concussions to which the mixtures might be subjected. In some instances, the protective action of these agents was such as to render that of the explosive less rapid and violent than that of gunpowder. Other attempts were more successful, and in these

instances a strong and comparatively safe compound was produced. This result was arrived at by mixing with the salt, substances containing, in addition to carbon, a considerable proportion of hydrogen, such as powdered nut-galls, resins, and tannin. Of the compounds thus prepared, that known as Horsley's may be taken as a typical, and the most successful example. This consisted of a preparation of chlorate of potash and powdered nut-galls in certain proportions; the results of experience showed that when prepared in this way the compound possessed great explosive force, and was of a comparatively safe character. But though Horsley's powder was applied somewhat extensively to blasting purposes, it is as a nitroglycerine compound that it deserves notice here. One of the attempts to which attention was directed in a former paragraph, was that of employing Horsley's powder as the absorbing medium for the nitroglycerine. In this case, the proportion of the latter was about 20 per cent., and the resulting compound was found to possess very violent explosive properties. This compound, which has been extensively applied to mining operations in Norway, is fired, like dynamite and lithofracteur, by means of a percussion fuse. It possesses an advantage over these latter explosives in not losing its susceptibility to detonation at low temperatures.

Brain's Blasting Powder.—The latest and the most successful attempt to produce a nitroglycerine compound superior in character to dynamite is that of Mr. W. B. Brain, the result of which attempt is seen in the explosive known commercially as Brain's blasting powder. This exceedingly strong explosive compound is remarkable as the outcome of sound chemical knowledge and exhaustive experiments. Its composition has been carefully considered, and the action of each of the constituents, both individually, and in common, accurately determined, in order that the end proposed might be fully and with certainty attained. The intelligence which has been exercised in the production of this explosive is sufficiently manifest in the success which has attended its application to the purposes for which it was designed. It has shown itself possessed of the qualities necessary in an explosive for common use, not the least of which qualities is its freedom from noxious fumes when exploded in confined situations. The merits, as well as the chemical composition, of this compound are clearly described and fully explained in the following report, prepared at the writer's request by Mr. Linford, consulting chemist, who possesses opportunities of rendering himself fully acquainted with the method of its manufacture, and with its behaviour in store, in transit, and in use:

"Brain's blasting powder consists of a base of chlorate of potash, or a mixture in varying proportions of chlorate and nitrate of potash, wood-charcoal, and prepared sawdust, which base is combined with 40 per cent., or less, of tri-nitroglycerine. In chemical composition this compound approaches nearest to the powder known as Horsley's, but it is much less costly, and the proportions of oxidizing and oxidable ingredients render it, in its strongest form, more powerful, and admit of greater variation in rapidity if required. It is superior to lithofracteur in having a more easily detonable base, and therefore generating more power with less nitroglycerine. For the same reason it is of course greatly superior to dynamite, which has an incombustible base; in fact, the No. 1 with 40 per cent. of nitroglycerine is a more powerful explosive than any dynamite I have yet seen with 75 per cent. From a number of experiments, I estimate its force as quite equal to pure tri-nitroglycerine. This at first sight seems an anomaly, but it is thus explained. The force of an explosive depends upon: 1. The amount of gas formed; 2. The density of that gas; 3. The amount of heat generated by the explosion; 4. The rapidity with which the gas is liberated. Practically we may

take nitroglycerine and guncotton, when detonated, to be the most rapid explosives in use, and gunpowder to be the slowest.

"The composition of glycerine and cotton is similar, each consisting of carbon, hydrogen and oxygen, but in somewhat different proportions, and in the nitro-compounds certain atoms of the hydrogen are replaced by NO_2. In the tri-nitroglycerine, the proportion of hydrogen so replaced furnishes oxygen sufficient to convert all the carbon into CO_2, carbonic acid, and indeed leave a portion in excess as N_2O. In the cotton, the proportion being less, the carbon is chiefly converted into CO, carbonic oxide. The remaining elements, oxygen and hydrogen, unite in the same proportion as they exist in the cotton, forming H_2O, or water in a state of vapour. Now H_2O, or water vapour, is not so dense a gas as CO_2, or carbonic acid, the relative weights being 9 and 22, and CO, or carbonic oxide, is between the two, or 14, so that it is easily seen that a cubic foot of CO_2 generated in the same time, and at the same temperature, produces more explosive force than the same bulk of CO, or H_2O; but it is a well-known fact that carbon oxidized to CO_2 generates about one-half more heat than the same amount of carbon oxidized to only CO.

"In Brain's powder we have, as will be seen from the above considerations, the required conditions thoroughly fulfilled; there is nitroglycerine in sufficient quantity to ensure instantaneity of detonation, while the excess of oxygen is also used up, together with all that in the chlorate, in producing, with the carbon of the wood and charcoal, carbonic acid; and, with the exception of the small amount of chloride of potassium formed, the whole is converted into gas as instantaneously as any other explosive. It is a misconception of the nature of a detonation to suppose the possibility of the nitroglycerine in such a mixture being detonated first, and the chlorate compound after. The chlorate and charcoal is the more easily detonated of the two, and really ensures the perfect detonation of the other. It is a fact acknowledged by all who use nitroglycerine, both in Europe and in America, that a powerful detonating charge, from 15 to 20 grains of fulminate, is required to ensure perfect detonation, and the same holds good of guncotton. Now I have exploded many charges of Brain's powder, never using more than 10 grains of fulminate, and never failed to detonate the entire charge. In fact, looking at the composition of the powder, I do not think it would be possible to detonate part of a charge either in the open air or in untamped holes. Dynamite, it is well known, generally leaves a vapour causing severe headache, showing that a portion must have been volatilized unburnt. Guncotton, as shown by an accident which occurred at Woolwich Arsenal, unless detonated with a powerful detonating charge, is often blown away; neither of which sources of loss are, I believe, possible with this powder, while the small amount of mineral matter, chloride of potassium, is more than compensated for by the density and temperature of the gas generated."

Guncotton.—Guncotton, nitrocotton, pyroxilin, or tri-nitrocellulose, was discovered by Schönbein in 1845, within two years of the discovery of nitroglycerine. The discovery of Schönbein showed that when cotton-fibre, or wood-fibre (cellulose), is submitted to the action of nitric acid, or a mixture of nitric and sulphuric acids, at ordinary temperatures, it becomes endowed with explosive properties, a proportion of the hydrogen in the cellulose being replaced by an equivalent amount of nitric peroxide. The degree of nitration of the cellulose, and the consequent explosive power of the product, vary with the strength of the acids employed, and also with the temperature at which the converting operation is conducted. Guncotton proper, or tri-nitrocellulose, $C_6H_73(NO_2)O_5$, is the most highly explosive of those substances yet known.

In the manufacture of guncotton, as in that of nitroglycerine, purity of the constituent sub-

stances is essential to the stability of the product, and, consequently, to the safety with which it may be handled. The means now adopted to obtain the requisite degree of purity in the materials, and the precautions taken to ensure uniformity in the resulting compound, are such as to render guncotton one of the safest explosives in use. The following description of the method of its manufacture, by Professor Abel, shows the nature of these means and precautions, and gives a clear notion of the form in which the explosive is produced.

"In the production of compressed guncotton, carefully selected cotton-waste is employed, in the place of the cotton-wool used in Schönbein's original process, and of the long staple cotton, spun into loose strands or threads, which was employed in Von Lenk's system of manufacture. The cotton is first carefully picked over, and submitted to a preparatory cleansing process if necessary. It is then opened up in a teasing machine, and cut into suitable lengths, with a view of facilitating its rapid immersion and impregnation in the acid bath. After having been thoroughly dried and allowed to cool in closed vessels, it is immersed, in small quantities at a time, in a perfectly cool mixture of 1 part of nitric acid (sp. gr. 1·52), and 3 parts of sulphuric acid (sp. gr. 1·85), and is afterwards allowed to remain for twenty-four hours in contact with about ten times its weight of the mixed acids, to ensure as complete a conversion as possible into guncotton. The vessels containing the cotton and acids are kept closed, and as cool as practicable; and, at the expiration of the proper period, their contents are transferred to a centrifugal extracting apparatus, by which the guncotton is separated to a great extent from the excess of acid. It is then suddenly plunged, by means of simple mechanical arrangements, in small quantities at a time, into a large volume of water. The object aimed at is to dilute the acid which remains in the guncotton with water so quickly as to avoid the development of heat, and the consequent establishment thereby of a secondary oxidizing action of the nitric acid upon the guncotton—an action which, even if of brief duration, might affect prejudicially the quality, and perhaps also the stability, of the product. The adoption of this precautionary measure, and the long-continued digestion of the guncotton with considerable excess of acids, constitute the prominent improvements which Baron von Lenk effected in Schönbein's process for producing guncotton. After this preliminary washing, the guncotton is drained of water by means of the centrifugal extractor; it is then rinsed twice in a large volume of water, and passed through the centrifugal machine after each rinsing. It is now transferred to a rag-engine, of the kind ordinarily used in producing pulp for paper-making. By this operation the guncotton is reduced to the state of fine division necessary for its subsequent conversion into homogeneous compressed masses: it is subjected, at the same time, to a most searching purification, which is continued in the next operation, the pulp being transferred to 'poaching' engines, where it is beaten about in a large volume of slightly warm water, which is renewed from time to time. This final washing operation is carried on continuously until the guncotton has passed satisfactorily through a searching test of purity. This method of washing constitutes one of the great advantages of the present system of manufacture. The chief obstacle to the complete purification of the guncotton consisted formerly in the obstinate retention of impurities within the hollow fibres. With a view to their removal, Von Lenk prescribed continuous washing during many weeks in running water, and subsequent boiling with very dilute alkali. But by the application of the pulping and poaching processes, the capillary action of the fibre is greatly reduced, and the washing operation is rendered so searching that a decidedly more complete and uniform purification of the material is accomplished in three days, at the outside, than was previously attained by processes which extended over six or eight weeks. At

the conclusion of the washing process, the guncotton pulp is impregnated with a small proportion of alkaline matter, and is then converted, by a preliminary moulding process, and subsequently by powerful hydraulic pressure, into compact masses of cylindrical and other forms, of about the same density as water, and of dimensions suited to the particular application required. During the whole of these manufacturing operations the guncotton is wet, and therefore absolutely uninflammable. After compression, the finished material is dried either in the open air or in heated chambers, where a rapid circulation of air is kept up. It is then packed in light wooden boxes for storage or transport. The drying process may be deferred for any time, and the damp, perfectly uninflammable guncotton stored in waterproof packages."

Guncotton is insoluble in water; but it is soluble in a mixture of ether and alcohol. The resulting solution is collodion. Guncotton is but little affected by heat until a temperature of 300° Fah. is reached; at that temperature it is decomposed, and burns away with abundant flame, or if confined, it explodes. It does not appear that shocks, however violent, are capable of producing an explosion in it.

When fired in the open air guncotton does not explode, but burns rapidly away with abundant flame, but without emitting smoke. When, however, it is fired in a confined situation, it explodes without producing either visible flame or smoke, and the violence of the explosion increases as the space within which the substance is confined becomes more limited. If fired in the open air by means of a detonating charge, guncotton explodes with great violence without producing flame. This property, which it possesses in common with nitroglycerine, gives it a great advantage over gunpowder in many situations. It is a curious fact that not all fulminating substances are capable of producing an explosion in guncotton, and that some of the most violent fail to produce that effect. Thus such powerful explosives as chloride of nitrogen and nitroglycerine are incapable of producing an explosion in guncotton, and the same minimum quantities of fulminate of silver and of fulminate of mercury are required, though the former is a more violent explosive than the latter. A long series of experiments has shown that the fulminate of mercury is the most suitable for the purpose, and that moreover this fulminate must, to produce the full effect, be contained by a substance capable of offering considerable resistance to its action. The character of the explosion which occurs in guncotton places this compound in the class of shattering explosives.

As a blasting agent, guncotton, like nitroglycerine, possesses some important advantages, and some serious defects. The absence of smoke allows the miners to return to their work much sooner after a blast with guncotton than with gunpowder, when combustion has been complete. But if the rock is fissured, or if the resistance opposed is insufficient to develop the full explosive force of the guncotton, the incomplete combustion results in the development of noxious vapours. One of the chief advantages of compressed guncotton lies in the convenient and safe form in which the charges are delivered to the miners, who may carry the discs about and handle them without much risk of accident. A defect, however, of this form, as compared with the plastic nitroglycerine compounds, lies in its inability to accommodate itself to the irregularities of the bore-hole. Other advantages possessed by guncotton are, that it is not at all injurious to handle, that its explosiveness is not affected by cold, and that it may be preserved for any length of time, without deterioration, in the damp and unignitable state. When all the properties of guncotton, physical and chemical, are taken into consideration, that compound appears to be less suitable for ordinary mining operations than those which have a nitroglycerine base.

Cotton Gunpowder.—Recently nitrocotton has been produced in a granulated form under the name of cotton gunpowder. For blasting in ordinary mining operations, this form of the compound removes one of the objections to compressed guncotton which, as we have shown, is manufactured in hard and unyielding discs. Beyond this, however, it is difficult to see what advantage is gained by the adoption of the pulverized form.

Means of Firing Explosive Compounds.—Recent research has led to the very important discovery that, in every explosive compound, two kinds of explosion may be produced. The value of this discovery, from a practical point of view, can hardly be over-estimated, since it opens up a way to very great economy of labour and material, and to increased expedition in the execution of work. The difference in these two kinds of explosion appears to be rather one of degree than of nature. It is probable that, in the one kind, the evolution of gases takes place *gradually* from one grain or molecule of the substance to another; while in the other kind, the evolution takes place *simultaneously* from all the grains or molecules. However this may be, the fact remains that a very important difference is observable in the effects produced by an explosion of the same quantity of the same substance under the same conditions, when the character of the explosion is changed from that of one kind to that of the other. Messrs. Roux and Sarrau, to whose researches the discovery of the possibility of producing two kinds of explosion is chiefly due, distinguish these two kinds as explosions of the *first* and of the *second order*. An explosion of the second order occurs when the substance is fired by the simple application of heat, as in applying flame to the substance; an explosion of the first order may occur when the substance is fired by the application of heat and force, as in the case of an explosion in it of some other substance. As an explosion of the first order is produced through the agency of a detonation, it may itself be called a "detonation," and the term "explosion" reserved for that of the second order. The manner in which a detonating substance operates in determining the detonation of another substance is enveloped in obscurity. A careful investigation of the subject by the most able men has hitherto failed to do more than show that the result cannot be ascribed to the direct action of the heat developed by the chemical changes which take place in the charge of detonating material employed as the exploding agent. Professor Abel remarks on this subject, that an experimental comparison of the mechanical force exerted by different explosive compounds, and by the same compound employed in different ways, has shown that the remarkable power possessed by the explosion of small quantities of certain bodies, as the silver and mercury fulminates, to accomplish the detonation of guncotton, while comparatively large bodies of other highly explosive agents are incapable of producing this result, is generally accounted for by the difference in the amount of force suddenly brought to bear in the different instances upon some portion of the mass operated upon. And that generally, therefore, the degree of facility with which the detonation of a substance will develop similar change in a neighbouring explosive substance may be regarded as proportionate to the amount of force developed within the shortest period of time by that detonation; the latter being, in fact, analogous in its operations to that of a blow from a hammer, or of the impact of a projectile. These views, however, are not supported by facts; and nothing remains, in the present state of our knowledge upon this subject, but to determine for every substance by actual experiment the nature and the quantity of the fulminating substance required to produce detonation. For the nitroglycerine compounds and guncotton, the fulminate of mercury has been found to constitute the most effective detonator. This explosive is, however, totally incapable of detonating gunpowder.

To produce detonation in any explosive substance, there are four conditions which must be satisfied. These are: 1. That the detonating charge employed shall be suitable in nature, and sufficient in quantity; 2. That the walls enclosing the detonating charge shall offer considerable resistance to the forces developed within them; 3. That the substance to be detonated shall surround the detonating charge; and 4. That the particles of which the substance to be detonated is composed shall not be liable to displacement.

The nature of the detonating substance employed is a question of primary importance. Frequently detonators are adopted which do not effect the purpose for which they are intended. With guncotton, which cannot be readily exploded by any substance other than the fulminate of mercury, no other is likely to be used. But with the nitroglycerine compounds, which may be fired by any explosive substance, there is a strong temptation to use a less costly detonator. It should, however, be borne in mind that such detonators are capable of producing an explosion of the second order only, and that consequently the larger portion of the force which the explosion is capable of developing is lost. It is only by detonation that the full force of an explosive can be utilized. The quantity of the detonating substance is likewise important. If the quantity be insufficient, either detonation does not take place at all in the charge, or it is not propagated throughout the mass; for it is possible for detonation to occur in one portion of the charge, and simple explosion in the rest. This singular occurrence will be illustrated hereafter. For ordinary small shot charges of the nitroglycerine compounds dynamite and lithofracteur, a detonator consisting of not less than 5 grains of fulminate of mercury should be used. In deep holes and larger charges, as much as 15, or, in some cases, even 20 grains will be required. For gunpowder, the writer has prepared a special detonator, which has been found to possess all the necessary conditions.

If the walls enclosing the fulminate of the detonator do not oppose considerable resistance to the forces generated within them by the explosion, detonation will not be produced. A charge of 5 grains of fulminate enclosed in a metal capsule is sufficient to detonate dynamite; but four times that quantity is insufficient to produce that result when paper is substituted for the metal. The action of a detonator upon the blasting charge is similar to that of a blow, and to obtain this sudden application of force, it is necessary to retain the gases evolved until the requisite force has been developed. If this condition be not satisfied, the effect will be the same as that resulting from the employment of an insufficient quantity of fulminate.

It is also necessary to certain detonation that the blasting charge should surround the detonating charge. If the latter be placed only in close proximity to the former, or even in contact with it, simple explosion may occur, or a portion of the charge may be detonated and the rest exploded in the second degree. To avoid such an occurrence, the detonator should be inserted to its full length in the charge when practicable. In every case, it must be at least partially inserted.

The condition which requires that the particles composing the blasting charge shall not be liable to displacement is of essential importance. The action of the forces developed by the detonating charge is to produce vibration in the particles of the charge to be detonated. This vibration is essential to detonation. It has been discovered by experiment that when a motion of translation occurs among these particles, the vibratory motion is not produced, or at least it is not produced in a degree sufficient to cause detonation. Hence it follows that if the particles of the blasting charge which are in contact with the detonator, or in close proximity to it, are free to move before the forces developed by the latter, detonation will not ensue, but only simple explosion.

The experiments of Messrs. Roux and Sarrau have certainly and clearly established this fact. In these experiments, cast-iron bombs, of equal dimensions, and practically of equal strength, were subjected to the action of an explosive charge fired within them. Repeated trials showed that 4 grammes of dynamite sufficed to burst the bomb when the charge was detonated, whereas 16 grammes were required to produce that effect when the charge was simply exploded. In continuing the experiments, the dynamite was placed loose in the bomb, and by no means could the latter be burst with a less charge than 16 grammes, a result which showed that the explosive had not been detonated. Next, 2 grammes of dynamite were placed loose in the bomb, and a cartridge also containing 2 grammes of the same substance, and enclosing a detonator, was inserted in it. When fired, this charge failed to rupture the bomb. The loose dynamite was then increased to 4 grammes, and with a like result. Finally the bomb burst with a charge of 6 grammes of loose dynamite and 2 grammes enclosed in a cartridge. These results showed that in no instance had the loose dynamite been detonated. The explanation of the failure of the detonated cartridge to cause detonation in the loose dynamite is to be found in the motion of translation produced among the particles of the latter. These particles underwent displacement, and were scattered by the forces brought to bear upon them by the detonation of the cartridge, and, consequently, the necessary vibration did not occur. On the contrary, when the explosive was enclosed by the walls of the cartridge, the opposition of these to motion among the particles enabled the latter to resist the forces of the detonator sufficiently for vibration to be produced. Experiments, leading to results similar to the foregoing, are recorded by Professor Abel, relative to guncotton. A bullet was fired from a rifle at a distance of 50 yards against a slab of compressed guncotton $\frac{3}{4}$ inch thick, and $3\frac{3}{4}$ inches in diameter, freely suspended in air by a string; the guncotton was, in this case, simply perforated by the bullet. A similar result was several times obtained with slabs of the same dimensions, and with others twice the thickness. On making the experiment with a slab three times the thickness, the guncotton was inflamed by the heat generated by the impact of the bullet, but not detonated. This experiment was repeated with the same result. But when subsequently the bullet was fired against a slab four times the thickness of that first employed, the result was detonation of the mass. In this instance the increased thickness and weight of the mass occasioned the resistance necessary to cause the requisite vibration.

It follows from this necessity for strong vibration in the particles and molecules of the substance to be detonated, that the nature of the material used as the absorbent in the manufacture of dynamite will influence, in no inconsiderable degree, the readiness with which detonation may be produced. Thus a plastic material like ochre, for example, must give rise to conditions unfavourable to detonation. On this ground also, the silica of the kieselguhr appears to be the most suitable yet employed. It is moreover evident, from the results of the experiments described in the foregoing paragraphs, that the retention of the grains of gunpowder by the walls of a cartridge will be favourable to the detonation of that substance. This retention, too, must be complete in every direction, for the existence of an empty space within the cartridge will prove an effectual obstacle to detonation. The required effect is more readily produced when the charge is slightly compressed, so as to put the grains into firm contact with each other. Such compression is besides advantageous in reducing the dimensions of a charge of a given weight. For these reasons the compressed gunpowder, to which attention was directed in a former paragraph, is very susceptible to detonation, and economical in use.

The following table contains the results of the experiments of Messrs. Roux and Sarrau, previously alluded to, and shows clearly the relative value of the effects produced by detonation and by simple explosion. In this table the explosive force of gunpowder developed by simple explosion is taken as unity.

RELATIVE STRENGTH OF EXPLOSIVE COMPOUNDS.

Substance Exploded.	Simple Explosion.	Detonation.	Relative weight of Gases.	Heat disengaged by 1 lb.	
				Simple Explosion.	Detonation.
				Units.	Units.
Fulminate of Mercury	..	9·28	..	..	1354
Gunpowder	1·00	4·34	0·414	1316	1318
Nitroglycerine	4·80	10·13	0·800	3097	3200
Guncotton	3·00	6·46	0·850	1902	1909
Picric Acid	2·04	5·50	0·892	1491	1563
Picrate of Potash	1·82	5·31	0·740	1417	1534

The evidence afforded by this table is very remarkable, and of the highest practical importance. There are two especially striking features in this evidence. The first is the enormous increase of force obtained by detonation, and the second is the singular fact that this increase is greatest in the common explosive gunpowder. It would be difficult to over-estimate the importance of these facts from a practical point of view. The ability to more than double the explosive force of the shattering compounds by the simple employment of suitable means for firing the substance must tend greatly to promote expedition and economy in the execution of future blasting operations. And the fact that by the adoption of such means gunpowder may be so changed in the character of its explosion as to become a shattering from a rending compound, possessing an available strength considerably more than quadrupled in value, will undoubtedly influence the future position of that substance among explosive compounds. Detonation has, it is true, been extensively practised with pure nitroglycerine, nitroglycerine compounds, and guncotton, but want of attention to the conditions of success leads to frequent failure. It is probable that in the majority of cases in which dynamite is fired by the ordinary means, certainly in a large minority of such cases, complete detonation is not produced. Sometimes a portion of the charge is detonated and the rest exploded; often only simple explosion occurs. To this cause must be attributed, in great part, the wide discrepancies which frequently appear in the results of experiments made with the same quantities of the same substance, and the seemingly anomalous differences between the effects of substances of different composition. By a suitable arrangement of the conditions under which the substance is fired, a dynamite containing 50 per cent. of nitroglycerine can be made to appear more powerful than another in which there is 75 per cent. of the latter substance. In practice, the conditions of detonation are often neglected, the result being the development of a force insufficient for the effect required, or the employment of a superfluous quantity of the explosive, and an evolution of noxious fumes consequent on incomplete combustion. For it should be borne in mind, that detonation is conducive, not only to economy of labour and explosive material, but to the wholesomeness of the atmosphere at the working faces. In close headings and in shafts this is a matter of weighty importance.

But to whatever extent the advantages of detonation may have been obtained from guncotton and nitroglycerine and its compounds, no such application has ever been made of gunpowder. In

ordinary practice, gunpowder is never detonated. Seldom, indeed, is any attempt made to produce that result; but even in the few cases in which detonation is sought, the means are frequently incapable of producing the effect desired. When the numerous and great advantages possessed by gunpowder are borne in mind, the importance of increasing its strength four and even fivefold is sufficiently obvious. It will appear from the foregoing table that dynamite containing 75 per cent. of nitroglycerine possesses a relative strength of 3·60 in single explosion, and of 7·60 in detonation. This is on the assumption that the nitroglycerine in mechanical combination with the absorbent material is capable of exerting the same force as when in a pure state. Thus gunpowder when detonated is much stronger than dynamite simply exploded, and the latter when detonated is superior to the former only in the ratio 1·75. If the merits and defects of the two compounds be fairly weighed, it will hardly appear that this superiority is sufficient to justify the claims often put forward for the nitroglycerine compound. But even this difference in strength may be lessened. Attention has already been directed to the E. S. M. blasting powder of the Messrs. Curtis and Harvey. This compound is, in consequence of its quicker action and the greater amount of heat disengaged, superior to common powder in simple explosion. But when fired by the special detonator, this powder is but little, if at all, inferior in strength to dynamite of the composition indicated above. But even if we admit the ratio of the strength of the No. 1 dynamite to be 1·75, the difference is much less than it is generally supposed to be. Notwithstanding this, however, cases will occur in which the superiority of the nitroglycerine compounds will be very marked; this will happen, for example, in the case of blasting in hard and very tough rock. Also the advantages offered by these compounds in wet ground are by no means to be overlooked. It should be remarked that, when gunpowder is detonated, a light tamping is sufficient.

Electrical Blasting Apparatus.—The employment of electricity to fire the charge in blasting rock, offers numerous and great advantages. The most important, perhaps, of these advantages, the ability to fire a number of charges simultaneously, will be considered hereafter, when treating of the principles of blasting. But another advantage, of no small moment, lies in the security from accidental explosions which this means of firing gives. By the employment of electricity, not only is the charge fired at the exact moment desired, when it has been clearly ascertained that all the workmen are under shelter, but the dangers due to misfires and the use of matches are avoided altogether. There are, it is true, other dangers to be feared, peculiar to the nature of electricity; but these may be lessened or removed by the employment of suitable means, and the adoption of simple precautions. Moreover, the facility afforded by electricity for firing charges under water constitutes a feature in this agent of no small practical importance. It would, therefore, seem, when all these advantages are borne in mind, that electricity is destined to become of general application to blasting purposes, and hence it is important to consider the means by which this agent is brought into use. It would, however, be beyond the scope of this work to investigate and explain the principles upon which the excitation and application of electricity rest. All that it is desirable to do here is to describe briefly the instruments commonly employed in the operations under consideration.

Electric Fuses.—An electric fuse, or, more correctly, an electric "exploder," consists of a charge of an explosive compound of a character capable of being acted upon by an electric current in a manner and in a degree sufficient to produce explosion. This charge is inserted in the cartridge or the capsule containing the detonating charge, and provision is made for conveying into it the current of electricity that is to decompose it. The mode in which this current is made to act may be one of

two kinds. In one mode, a very fine platina, iron, or an alloyed metal wire is inserted in the charge, and included in the circuit of a powerful voltaic battery. The resistance offered by the diminished conducting power of the fine wire to the passage of the electric current heats the wire to redness, and the heat thus developed causes an explosion of the compound in contact with the wire. The conditions to be observed in this case are: to develop a large quantity of electricity; to provide conducting and return wires of sufficient sectional area; and to seal the fine wire to be heated within the charge to be exploded. In the other mode, a sudden discharge of static electricity is made to take place between the terminals of two wires embedded in the compound composing the charge. The conditions to be observed in this case are: to provide means of exciting and accumulating static electricity; to employ suitably placed and, where necessary, insulated conducting and return wires; and to include between these a compound capable of being exploded by the passage of the spark between the terminal points. The latter is found in practice to require the more simple appliances, and to be in consequence the more certain in action.

In the design and manufacture of fuses constructed upon the principle of an electric discharge, there are certain difficulties to be overcome, and certain dangers to be avoided. It is essential to isolation that the terminal points of the wires be separated by a considerable space, one-sixteenth of an inch being the minimum distance allowable. But as the electric spark cannot be made to leap a great distance, it is necessary that the compound itself, which is to be exploded by the spark, shall possess some degree of conducting power. It is obvious, however, that the conductibility of this compound must not be sufficient to allow of the passage of the current; and hence arose a necessity for numerous experiments to determine the composition of the explosive substance. An element of danger, to be as far as possible eliminated, lies in the too great sensitiveness of the compound. Many serious accidents have been occasioned by this property. Several compounds have been proved to fulfil the requisite conditions in a satisfactory manner, and have been largely adopted in practice. Of these, that which was discovered by Professor Abel is perhaps the most widely employed at present. It consists of an intimate mixture of chlorate of potash and subsulphide and subphosphide of copper, in certain proportions, the copper being introduced to give the required conducting power. The proportions adopted are: subphosphide of copper, 10 parts; subsulphide of copper, 45 parts; and chlorate of potash, 15 parts. These substances are well rubbed together in a mortar, with the addition of sufficient alcohol to thoroughly moisten the mass. The mixture is afterwards carefully dried, and it may then be safely preserved in closed vessels until required. The following description of the Abel fuse is given by the inventor in a memoir published on the subject.

"The fuse-head, which is of wood, contains three perforations, as shown in Figs. 357 and 358; the one passing downwards through the centre receives about 2 inches of double insulated wire *a a*, two copper wires of 24 gauge, 0·022 inch diameter, enclosed side by side at a distance $\frac{1}{16}$ inch, in a coating of guttapercha of $\frac{1}{8}$ inch diameter. The other two perforations, which are parallel to each other on each side of the central one, and at right angles to it, serve for the reception of the circuit wires. The arrangement for securing the connection of these with the insulated wires in the fuses is as follows:

"The piece of double-covered wire above referred to is originally of sufficient length to allow of the guttapercha being removed from about $1\frac{1}{2}$ inch of the wires. These bare ends of the fine wires, which are made to protrude from the top of the fuse-head, are pressed into slight grooves in the wood, provided for their protection, and the extremity of each is passed into one of the horizontal perfora-

tions in the head, in which position it is afterwards fixed by the introduction into the hole of a tightly fitting piece of copper tube, so that the wire is firmly wedged between the wood and the exterior of this tube; thus it is brought into close contact with a comparatively large surface of metal. It will be seen that it is necessary only to fix one of the circuit wires into each of these tubes, in opposite sides of the fuse-head, in order to ensure a sufficient and perfectly distinct connection of each of them with one of the insulated wires in the fuse.

"The extremity of the double-covered wire, which protrudes to a distance of about $\frac{3}{4}$ inch from the bottom of the fuse-head, is provided with a clean sectional surface by being cut with a pair of sharp scissors, care being taken that the extremities of the fine copper wires be not pressed into contact by this operation. A small cap of about $\frac{1}{2}$ inch in length is constructed of thin tinfoil, into which is dropped about one grain of the priming material. The double wire is then inserted into the cap and pressed firmly down, so that the explosive mixture is slightly compressed and in close contact with the surfaces of the wire terminals, as shown in Figs. 358 and 359. The cap is fixed by winding a piece of twine once or twice around its upper parts; tightening the ends of this, and then removing it. The fuse is then ready for enclosure in the detonating charge. The latter is contained in a paper case tied on to the head, or in a cylinder of sheet-tin tightly fitting on the fuse-head at one end, as shown in Figs. 360 and 361; the other end, after the introduction of the charge, is closed with a plug of clay or plaster of Paris. It is advisable to have the fuses ready fitted with pieces of insulated wire about 2 feet in length, and twisted together, as shown in Fig. 362. The ends of the wires, after they have been passed through the connecting holes in the fuse-head, should be tightly fixed in their positions by the introduction of a short piece of copper wire."

A compound of a character similar to Abel's was used by George Mowbray, an eminent American chemist, in the manufacture of the electrical fuses employed in the Hoosac Tunnel. This compound consisted of sulphide of copper, 9 parts; subphosphide of copper, 2 parts; chlorate of potash, 3 parts; the whole intimately mixed. This chemist subsequently substituted silver for the copper sulphide and phosphide of the Abel composition, as being a better conductor. Thus constituted, the priming compound consisted of: phosphorus, 5 parts; sulphur, 15 parts; silver, 100 parts; mercury, 25 parts; and chlorate of potash, 30 parts. And still later, a new compound, consisting of 3 parts of mercuric sulphide and 1 part of chlorate of potash, was adopted. Mowbray thus describes the mode of manufacturing his fuses:

"The priming compound is prepared by myself, to ensure uniformity and a proper combination of the ingredients, and then passed on to the filling house, where it is made up into exploders. Two insulated wires, from 4 to 12 feet long, are inserted into a moulded guttapercha plug, $\frac{3}{4}$ inch in length and $\frac{1}{8}$ inch in diameter at one end, and $\frac{3}{16}$ inch at the other, to which they are fastened by a weld of guttapercha. Immediately before the priming is inserted, an electric spark is passed through and between the wires where the priming is put, to ascertain that the insulation is perfect, so as to prevent the possibility of misfire. This being proved, the priming is put in, and a small paper plug, boiled in paraffine, inserted. Then, a copper cap, $\frac{3}{4}$ inch in length and $\frac{3}{8}$ inch in diameter, receives the detonating charge of fulminate mercury, on the top of which a varnish is poured to prevent the fulminate from being shaken out by accident, or affected by vibration. This copper cap having been previously covered with a guttapercha envelope, the electric fuse is inserted about $\frac{1}{4}$ inch, and cemented tight; the parts are afterwards painted with asphaltum varnish around the joints, when the exploder is complete and ready for service."

Numerous other compounds are used in electric exploders; indeed, they may be varied in an almost unlimited degree. A common one consists of chlorate of potash and sulphide of antimony in equal parts. The essential conditions to be observed are: that they shall be uniform in their composition; that they shall offer neither too great nor too little resistance to the spark; and that they shall not be so sensitive as to explode from the ambient electricity of the atmosphere, or from a light concussion in handling.

A very simple, effective, and cheap form of electric fuse is in common use: it is known as the "blasting stick." It consists of a thin lath of wood, 3 feet in length, $\frac{5}{8}$ inch in breadth, and about $\frac{1}{4}$ inch in thickness, armed at one end with a detonator, in which two fine wires, preferably of copper, are lodged. The detonator consists of a metal cap containing the detonating charge and the priming compound into which the wires are led. These wires, insulated by a coating of guttapercha, or of asphaltum applied hot, are lodged in saw grooves made in the face of the stick for that purpose. Instead of the saw grooves being made to receive the wires, the stick is frequently composed of two thin strips glued together, with the wires lodged between them. Fig. 363 represents one of these blasting sticks.

In using the blasting stick, the detonator is placed in the blasting charge, and the hole tamped, with the stick standing against the sides of the hole. To fire the charge, the end of one of the wires is connected with the conducting wire from the electrical machine, and the end of the other with another wire which connects it with one of the wires on the stick in the next adjacent hole. The other wire of this second stick is connected by the same means with one of the wires of the stick in the third hole, and so on till the whole number of charges are connected. The end of the second wire in the last hole is connected with the return wire from the machine. In this way as many as fifty shots may be fired at once. In making the connections, the insulating coating must be scraped off the ends of the wires for a length of about two inches, and these uncovered portions twisted together in the manner shown in Fig. 364, care being taken to keep the ends close down to the wire, and not sticking out, in the manner shown in Fig. 365. In wet situations a small guttapercha tube may be drawn over the joint, the end of one of the wires having been passed through the tube previously to the joint being made. This tube should extend beyond the uncovered portions of the wires, and be bound to them with twine, as shown in Fig. 366. Abel recommends the joint shown in Fig. 367. The ends of the wires in this instance are hooked firmly into each other by the application of pliers. A piece of fine copper binding wire, about 6 or 8 inches in length, is then bound over the whole of the connection, and finally enclosed in a small wrapping of oiled canvas.

Conducting Wires, Insulators, and Supports.—The conducting wires used in blasting may be either of copper or of iron. The former is the better conducting medium, and as it also possesses the advantage of greater toughness, it is the most commonly employed. The sectional area of the wire is largely concerned in its conducting power; the resistance is found to vary inversely as the sectional area, and hence it is important to give the conducting or circuit wires a sufficient diameter. As a portion of these wires is necessarily destroyed at every blast, there is a temptation to reduce the weight of the wire used to the lowest possible limits, for the sake of economy. But it will be found more conducive to economy in the end to be somewhat lavish in this direction. A suitable weight of copper wire is 250 grains a yard; this weight gives a diameter of about $\frac{1}{10}$ inch. Wire of this diameter constitutes a good conducting medium, and is inexpensive. When covered with guttapercha, it is easily portable, very flexible, and capable of being readily coiled upon a reel. Two miles

of this wire will easily pack into a cubic yard. The prices range from 10*l.* to 20*l.* a mile, the difference being due to the greater or less quantity of the guttapercha covering. For firing charges upon land, where a return wire is always necessary, the lowest priced wire is sufficient in every case. It is a good plan to compose the conducting wires of three strands twisted together as a rope. The advantage of this form is greater flexibility, and less liability to rupture. A single strand of wire having the same weight per unit would convey electricity equally well; but it soon becomes hard and unmanageable, and is then very liable to break at the bendings. The twisted wire is less strained by being bent, and even when one of the strands gets broken, the other two are capable of transmitting the current.

To insulate the circuit wires, they are covered with a coating of guttapercha. This substance appears to be the only one suitable for the purpose. Various other materials have been substituted for it, and it has been employed, for the sake of cheapness, adulterated with other substances, such as pitch, clay, and plaster of Paris. But the results obtained were, in every case, of an unsatisfactory character. Besides the guttapercha for insulation, a covering of tape is needed for the protection of the insulating coating. Sometimes a coating of a solution of shellac is laid over the tape covering, and a varnish is put over this again, for the better protection of the wire.

Not unfrequently ordinary iron telegraph wire is used for the circuit wires. In such cases no covering is applied, and consequently insulators may be required at the points of support. The common stoneware insulators are the most suitable for this purpose; they may be fixed in the usual manner upon a wooden arm, about 2 feet in length, nailed upon the top of a stake or a pole, when the wires have to be carried over the surface of the ground. In headings, the insulators may be fixed to the timbers of the roof. In all cases the circuit wires should be fixed to the roof timbers, because when in that situation they are out of the way of the workmen, and are not liable to be flapped against the sides or dropped upon the floor.

Electrical Machines.—The apparatus required to excite and to accumulate electricity may be of several kinds. Thus we may have a frictional electrical machine and Leyden jar; a voltaic battery, with induction coil; an electro-dynamic machine, such as Siemens', or Gramme's; or an electro-magnetic machine, as Wheatstone's, or Clarke's. Of these, however, only one, namely, the frictional machine, is suitable for ordinary blasting operations. The conditions of mining are such as to render simplicity of construction and action an essential quality in a machine, and this quality is possessed only by the frictional electrical machine. Many forms and modifications of this machine have been devised, for the purpose of rendering it suitable to the requirements of practice. The main objects of these devices have been the attainment of simplicity and strength of parts, and the provision of means for protecting the parts from the influence of moisture. The importance of such a protection will be obvious, when the usually wet character of the situations in which mining operations are carried on is borne in mind. One of the best of these improved machines is that of A. Bornhardt, of Brunswick, which will be found illustrated on Plate XXXII., Figs. 368 to 371.

The circular friction plate F is of vulcanized guttapercha, and turns upon an iron axle *a*, which is furnished with a pinion *b*. This pinion is driven by a toothed wheel *c* four times its diameter, to give velocity to the plate. The driving wheel *c* is turned by means of the handle *d* on the outside of the wooden case or box in which the machine is contained. The rubber R is held up against both sides of the plate by a spring H. The collecting rings J collect the electricity as it is excited, and charge the condenser jar L with it. This jar is set in a wooden base or support fixed to the casing;

the forward side of the jar is covered with a guard or shield of vulcanized guttapercha, to prevent a discharge of electricity from the plate to the external covering of the jar. The discharge of the jar is effected through the medium of the conductor G, which is pressed into contact with the latter by means of the button K, as shown by the dotted lines, against the pressure of a spiral spring which tends to hold it in communication with the ring C. The ring D is in metallic communication with the external covering of the jar. In order to ascertain easily the normal condition of the machine, a scale of fifteen metallic buttons is provided at X, which scale may be put in communication with the rings C and D through the medium of chains, as shown in the figures. If, after fifteen or twenty turns, the spark leaps the intervals of the scale, when the button K is pressed in, the machine is in good condition. The joints of the wooden casing are made air-tight, to protect the internal parts from the influence of moisture. The outside dimensions of the casing are 20 inches in length by 14 inches in depth, and 7 in breadth, and the whole does not exceed 20 lb. in weight; thus it will be seen that this machine is simple in construction, well protected, easily portable, and not likely to get out of order. It is capable of firing any number of charges up to thirty.

This machine may be lodged in any suitable place underground. To fire the charges by means of it, the leading wire is hooked into the ring D, and the return wire into the ring C, the other ends being connected to the fuses in the manner already described. The handle is then put on, and from ten to fifteen turns given to excite the electricity. It is then necessary only to press in the button or knob K to produce the discharge, and the consequent explosion of the blast. To give additional security to the men engaged, the handle *d* is designed to be taken off when the machine is not in actual use, and the end of the machine, into which the circuit wires are led, is made to close with a lid and lock, the key of which is always in the possession of the person in charge of the blasting operations.

George Mowbray has introduced into use in America a frictional electric machine, similar in design to that of Bornhardt's, but possessing some improvements in the details of its construction which render it, perhaps, the most perfect of its kind. The patentee has adopted the cylinder for an exciting surface, because "the cylinder machines have a superiority in their exciting power over plate machines of equal surface in the proportion of four to one."

It may be desirable to add here one word of caution with respect to the use of over-sensitive fuses, and the careless handling of the bare wires. The dangers proceeding from these sources were observed by Mowbray in his experience at the Hoosac Tunnel, and recorded by him in the following words:

"It is important that the fuses shall not be so sensitive as to explode, either from the ambient electricity of the atmosphere, or from the electricity pervading a tunnel, and caused by the friction of the air from the compressors when it escapes through the vulcanized rubber of the connecting pipe. This source of electricity, I believe, caused an accident in March, 1873, attended with fatal results, which accident was followed by another, similar in every respect, a fortnight later. For as the blaster charging the holes on that occasion observed: 'The moment I touched the bare wire, after the insulated portion had passed through my hand, premature explosion ensued.' It had been the custom, after withdrawing the drilling machines, to allow a pretty free discharge of compressed air, for ventilation; and assuming a man in his rubber boots to be an insulated jar, the hands, face, &c., would serve as collecting points, whilst the electricity developed by the moist vesicles of the cold, expanding air rushing through a pipe from a reservoir charged up to 50 or 60 lb. to the inch, would

resemble in its source that obtained by the hydro-electrical machine. The blaster, unaware that he is a walking charge of electricity, proceeds to his work, inserting cartridge after cartridge of the explosive compound, until he comes to the last, which is armed with the electric fuse. The moment his hand touches one of the naked wires the current passes through the priming, and an explosion follows. Let, therefore, a blaster, before he handles these wires, invariably grasp some metal in moistened contact with the earth, or place both hands against the moistened walls of the heading. Also, before taking the leading wires to the electric fuse wires, let the bare ends of the leading and return wires be first brought into contact with each other, and then into contact with the moist surface of the heading, or with some metal in good connection with the ground; and before inserting the armed cartridge, let him unite both of the uncovered wires, and touch them against a metal surface having good ground connection. But, above all, it is desirable not to ventilate, by allowing a free blast of air through a rubber pipe, until after the electric connections have been made and the blast fired."

The Principles of Blasting.—The principles upon which the operations of blasting are conducted are few and simple. Yet it may be doubted whether they be more than imperfectly understood by those who conduct such operations. Very frequently, holes are bored in certain positions, and the explosive substance is inserted in certain quantities for no better reason than that such things have been done before. The inevitable consequences of this ignorance are, slow progress in the execution of the work, and a large consumption of material. There are, indeed, few engineering operations offering such a field for the exercise of economy as that of blasting, or one in which the end proposed may be so easily attained. By a skilful application of an accurate knowledge of the manner in which an explosion acts, and of the structure and mineral composition of rocks, a reduction in the number of the bore-holes and in the quantity of the explosive required may be made, and a rapidity of progress attained, no less remarkable and important than the results attendant on the adoption of machine drilling. It is therefore desirable, before quitting the subject of blasting, to point out and explain the principles which should guide the conduct of the operations.

It has already been said that an explosion is a sudden transformation of a substance from the solid or liquid into the gaseous form. The action is similar to that which goes on in a steam boiler. The application of heat to the water contained in the boiler transforms that substance from the liquid into the gaseous form, and as the gases into which the liquid is converted tend to occupy a much larger volume than the liquid from which they are derived, a pressure is caused tending to burst the boiler, and the intensity of this pressure will depend upon the relative volume of the gas. In that case, the transformation of the water into gas proceeds slowly, and the full effects are not obtained until after a considerable lapse of time. If, however, the water could be suddenly flashed into steam, as happens when a jet is directed upon a red-hot iron plate, the full pressure would be produced at once, and a result very much like an explosion would ensue. If, instead of the water, gunpowder were placed in the boiler, and heat applied, when a certain degree of temperature was reached, the powder would flash into gas, in the same manner as we have supposed the water to flash into steam, and the same effect of pressure would be produced on the boiler. The pressure of a fluid, it must be borne in mind, is exerted equally in all directions, and, consequently, every square inch of the metal will be subjected to the same strain. Hence it is obvious that if the boiler bursts, it will yield in the weakest parts, and the line along which the fracture would run in such a case is called *the line of least resistance.* It will appear from the foregoing that an explosion is merely the sudden

application of great pressure; so sudden, indeed, as to partake of the character of a blow. But though the forces developed are thus suddenly applied, their action is in all respects the same as when the application is gradual and slow, and in considering their action, therefore, it is only necessary to assume a slow evolution of gases to determine it with precision.

As in the steam boiler the full pressure is not attained until the whole of the water has been converted into steam, so in the case of an explosive compound, the full pressure upon the containing body is not developed until the whole of the substance has been converted into gas. When gunpowder is fired in the open air, the gases escape as they are formed, and the pressure developed upon the body upon which the substance rests is equal to the resistance opposed by the air to the escape of the gases. The value of this resistance will obviously increase with the velocity possessed by these gases. It is the pressure due to this cause that forces the rocket to ascend, and it is evident, from the relation subsisting between the pressure exerted and the velocity of evolution of the gases, that the more rapid the combustion of the substance, the greater will be the velocity of ascent. If the rocket-case were made sufficiently strong, and the gases retained within it until the whole of the substance was transformed, the pressure exerted against the inside of the case would continue to increase as the transformation was effected; and if, when the latter was complete, the gases were allowed to suddenly escape from the end, the rocket would ascend with the maximum attainable velocity, or if retained in its position, the gases would exert upon it their maximum lifting force. These facts explain the difference in the effects produced by the slow and the quick explosives when fired in the open air. When gunpowder, for example, is fired in this way upon a stone, the downward pressure developed is not great; but when nitroglycerine is fired by detonation under the same conditions, the stone is crushed or fractured. Even gunpowder will produce similar effects if detonated. The different pressures produced in these cases are chiefly due to the differences in the rapidity with which the transformation of the substance takes place. Hence we see the value of detonation. When a substance is detonated, the vibration caused by the detonator produces a simultaneous evolution of gases from each molecule of the substance detonated, and consequently the maximum force is developed at once, instead of gradually, as in simple explosion.

Suppose now a charge of slow explosive placed in a vertical bore-hole in strong rock, and fired. Here the gases can escape only in one direction; and as the area upon which the air presses is much less than when the charge was exposed on all sides but one, the velocity of the air must be much greater to allow the same volume of gases to escape in the same time. Consequently the pressure exerted upon the bottom of the hole will be greater than that exerted upon the stone; and as the pressure is necessarily equal in all directions, the same pressure will be exerted against the sides of the hole. As the action of the explosive is quickened,—assuming this condition possible—the resistance of the air, and consequently the pressure upon the bottom and sides of the hole, will increase until its maximum is reached when detonation or instantaneous transformation is effected. This maximum, it must be borne in mind, is necessarily equal to the resistance opposed by the atmosphere; and though it may be sufficient to fracture the rock, it does not represent the whole of the force developed by the explosive. A large proportion is expended in giving velocity to the air in the bore-hole, and another portion is lost as heat communicated to the rock. The quantity of heat lost in detonation is less than in simple explosion, because the gases are in contact with the rock during a shorter interval of time. Thus a larger proportion of the force developed is rendered available by detonation. Moreover, as gunpowder, when detonated, may be used in much smaller

quantities, the surface of rock exposed to the gases will, by such means, be proportionately reduced, and, consequently, the loss of heat will be lessened in a like degree. This constitutes another source of economy of the force developed by the explosion. But as the greatest loss is occasioned by the comparatively slight resistance of the air in the bore-hole, the most important saving is to be sought in this direction. It is obvious that by substituting for the air a more strongly resistant substance, a larger proportion of the force developed may be rendered available; in other words, a proportionately greater pressure will be exerted upon the sides of the bore-hole. By this means, which is known as "tamping" the hole, a sufficient force may be thrown against the sides of the hole to fracture the rock, which is the end proposed in blasting. It is also obvious that economy of force requires that the materials employed as tamping should be of the most resistant character obtainable. Those which are available for this purpose will be hereafter considered.

Line of Least Resistance.—As the pressure of a fluid is exerted equally in all directions, the surrounding mass subjected to the force will yield, if it yield at all, in its weakest part, that is, the part which offers least resistance. The line along which the mass yields, or line of rupture, is called, as we have already stated, the line of least resistance, and is the distance traversed by the gases before reaching the surface. When the surrounding mass is uniformly resisting, the line of least resistance will be a straight line, and it will be the shortest distance from the centre of the charge to the surface. Such, however, is rarely the case, and the line of rupture will therefore in most instances be an irregular line, and often much longer than that from the centre direct to the surface. It will be obvious, on reflection, that the line of least resistance will be greatly dependent upon the texture of the rock, which may vary from one point to another; its structure, which renders it more easily cleavable in one direction than in another; the position, number, and direction of the joints which separate the rock into more or less detached portions; and the number and relative position of the unsupported faces of the rock. All of these circumstances must be ascertained, and the position of the bore-hole determined in accordance with them, in order to obtain the maximum effect from a given quantity of explosive. It must not be supposed that this is a labour involving minute examination and long consideration. On the contrary, a glance is generally sufficient to enable the educated eye to estimate the value of the circumstances before mentioned, and to determine accordingly the most effective position for the hole. The ability to do this is always claimed by workmen. They can *see*, they say, which is the best position for the charge. To those who possess the requisite knowledge of rock structure and the action of expanding gases, the determining circumstances are certainly apparent. But in a great majority of cases, this *seeing* amounts to little more than following the famous rule of thumb. And if there be one operation less subject to this rule than any other, it is that of blasting, in which the conditions vary from hole to hole. The possession of such knowledge should, therefore, be deemed essential. Without it, every blast is necessarily of a tentative character; and to ensure the attainment of the end proposed in such cases, a superfluous quantity of the explosive compound is employed. Nor is this the only waste due to the same source; even by the expenditure of an additional quantity of the explosive, the work can seldom be effected without distributing this quantity among a larger number of holes. The object to be aimed at by the blaster is the accomplishment of a given quantity of work with the least labour of boring, and the least expenditure of powder. To attain this object, the first condition evidently is, to determine accurately the line of least resistance, or in other words, the most effective position for the bore-hole. In practice, the line of least resistance is taken as the shortest distance from the centre of the charge to the surface of the rock,

unless the existence of natural divisions or differences of texture shows it to lie in some other direction.

Force required to Cause Disruption.—When the line of least resistance is known, it remains to determine the quantity of the explosive compound required to overcome the resistance along that line. This matter is also one of great importance, for not only is all excess waste, but this waste will be expended in doing mischief. In mining operations, the dislodged rock is violently projected, to the injury of the sides of the heading or the shaft, and the air is fouled in an unnecessary degree; and in quarrying, stones are shattered which it is desirable to extract in a sound state. Of course, it is not possible so to proportion a charge to the resistance that the rock shall be just lifted out, and no more, because neither the force developed by the charge nor the value of the resistance can be known with precision. But a sufficient approximation may be easily arrived at to enable us to avoid the loud report that is indicative of what may be called "superfluous" waste. The lavish expenditure of powder which is everywhere made does no honour to the mining engineering profession, and it becomes all interested to direct attention to this matter. The common miner, or quarryman, acting in accordance with his rule of thumb, fills his bore-hole up to a certain height with the explosive substance, and this condition must be fulfilled irrespective of the diameter of the hole, the nature of the rock, or the length of the line of least resistance along which the rock will be fractured. More than this, the rule must be followed irrespective of the strength of the explosive, for not unfrequently dynamite, even, is made to fill the same portion of the hole as gunpowder. This source of waste claims immediate attention, and opens a wide field to economy.

Charges of powder of uniform strength produce effects varying with their weight, that is, a double charge will move a double mass. And as homogeneous masses vary as the cube of any similar line within them, the general rule is established that charges of powder capable of producing similar results, are to each other as the cubes of the lines of least resistance. Hence, when the charge requisite to produce a given effect in a particular substance has been determined by experiment, that necessary to produce a like effect in a given mass of the same substance may be readily determined. As the substances to be acted upon are various, and differ in tenacity in different localities, and as, moreover, the quality of the powder may vary considerably, it will be necessary, in undertaking mining operations, to make experiments in order to determine the constant which should be employed in calculating the charges. Generally, the charge of ordinary blasting gunpowder requisite to overcome the resistance will vary from $\frac{1}{25}$ to $\frac{1}{35}$ of the cube of the line of least resistance, the latter being measured in feet, and the charge in pounds. Thus, if the material to be blasted be moderately strong sandstone, and the length of the line of least resistance 3 feet, we shall have $3 \times 3 \times 3 = 27$, and $\frac{27}{30} =$ the weight in pounds of gunpowder required. Also, if the line of least resistance be 4 feet, we shall require $\frac{4 \times 4 \times 4}{30} = \frac{64}{30} = 2\frac{2}{15}$ lb. to produce rupture, the proportion for sandstone being taken as $\frac{1}{30}$. Of course, when a stronger explosive than gunpowder is employed, a proportionately smaller quantity must be taken. Thus, if we assume dynamite to be five times the strength of gunpowder, the foregoing proportion must be reduced in a corresponding degree; that is, instead of $\frac{1}{30}$, we must take $\frac{1}{30 \times 5} = \frac{1}{150}$. It is neither practicable nor desirable that such calculations and measurements as these should be made for every blast; their practical value lies in this, namely, that if the principles involved in them be clearly understood, the blaster is enabled to

proportion his charges *by sight* to the resistance to be overcome, with a sufficient degree of precision.

One pound of gunpowder of average specific gravity occupies, when loosely poured out, about 30 cubic inches, and one cubic foot will thus weigh $57\frac{1}{2}$ lb. Consequently, a hole one inch in diameter will contain 0·416 oz. for every inch of depth. Hence, to find the weight of powder to an inch of depth in any given hole, we have only to multiply 0·416 oz. by the square of the diameter of the hole in inches; and in this way we may determine, either the length of hole for a given charge, or the charge in a given space. The following table will be found of practical value:

Diameter of the Hole.	Powder contained in an inch of length.	Powder contained in 1 foot of length.	Depth of Hole to contain		Diameter of the Hole.	Powder contained in an inch of length.	Powder contained in 1 foot of length.	Depth of Hole to contain	
			$\frac{1}{4}$ lb. of Powder.	1 lb. of Powder.				$\frac{1}{4}$ lb. of Powder.	1 lb. of Powder.
in.	oz.	lb. oz.	in.	in.	in.	oz.	lb. oz.	in.	in.
1	0·416	0 4·992	9·615	38·461	$2\frac{3}{4}$	3·175	2 6·100	1·259	5·039
$1\frac{1}{4}$	0·650	0 7·800	6·153	24·615	3	3·744	2 12·928	1·068	4·273
$1\frac{1}{2}$	0·936	0 11·232	4·273	17·094	$3\frac{1}{4}$	4·394	3 4·728	0·910	3·641
$1\frac{3}{4}$	1·274	0 15·288	3·139	12·558	$3\frac{1}{2}$	5·096	3 13·152	0·784	3·139
2	1·664	1 3·968	2·403	9·615	$3\frac{3}{4}$	5·850	4 6·200	0·683	2·735
$2\frac{1}{4}$	2·115	1 9·380	1·891	7·565	4	6·656	4 15·872	0·600	2·403
$2\frac{1}{2}$	2·600	1 15·200	1·534	6·153					

Blasting holes are never bored truly circular; but the variations of the quantity, as determined by the table, due to this circumstance are of no practical importance.

Tamping.—It will be apparent from the foregoing considerations that the operation of tamping the bore-hole, and the materials to be employed for that purpose, are questions of the highest importance in blasting. The object of tamping is to oppose a resistance to the escape of the gases in the direction of the bore-hole superior to that offered by the rock along the line which has been determined as that of least resistance. That is, the use of the tamping is to prevent the line of the bore-hole being that of least resistance. Hence, a primary condition is that the materials employed shall be of a strongly resistant character. A second determining condition is that these materials shall be of ready application. This condition precludes the use of all such devices as plugs, wedges, and forms of a similar character, which have been from time to time proposed. The only material that has been found in practice to satisfactorily fulfil the requirements demanded is rock in a pulverulent state. As, however, all rock is not equally suitable, either from the point of view of its resistant character, or from that of convenience of handling, it becomes necessary to consider which satisfies the two conditions in the most complete manner.

Though it is not easy to assign a perfectly satisfactory reason why one kind of rock substance opposes a greater resistance to motion in a bore-hole than another, yet it is certain that this resistance is due to the friction among the particles of that substance. If a column of solid, hard rock, of the same diameter as the bore-hole, be driven down upon the charge, the resistance opposed by the column to the imprisoned gases will be, neglecting the weight of the former, that of the friction between the sides of the column and those of the hole. But if disintegrated rock be used, not only is an absolute motion imparted to the particles, but, on account of the varying resistances, a relative motion also. Consequently, friction occurs amongst the particles, and as the number of these is immense, the sum of the slight friction of one particle against another, and of the great friction

of the outside particles against the sides of the hole, amounts to a much greater value than that of the outside particles of the solid column against the sides of the bore-hole. If this view of the facts alone be taken, it follows that dry sand is the most resistant material, and that the finer the grains the greater will be the resistance which it offers. In practice, however, it has been found that though the resistance offered by sand tamping is very great, and though also the foregoing inference is true when the tamping is lifted by the pressure of a solid against it from below, this substance is notably inferior to some others when acted upon by an explosion of gases. The explanation of this apparent anomaly is that the gases, under the enormous tension to which they are subjected in the bore-hole, insinuate themselves between the particles, and so prevent the friction which would otherwise take place. When the readiness with which water, through the influence of gravity alone, permeates even closely compacted sand is borne in mind, there will be no difficulty in conceiving a similar action on the part of more subtile gases in a state of extreme tension. Under such conditions as these, there is no resistance whatever due to friction, and the only resistance opposed to the escape of the gases is that proceeding from the inertia of the mass. How this resistance may be very great, we have shown in the case of air tamping. Hence, it becomes necessary to have recourse to some other material, of a composition less liable to be thus acted upon, or to seek means of remedying the defect which renders such action possible.

Clay, dried either in the sun or, preferably, by a fire, appears to fulfil the requirements of a tamping material in the fullest degree. This substance is composed of exceedingly minute grains of silicious matters, bound together by an aluminous and calcareous or ferruginous cement. Thus constituted, there are no voids between the particles as in porous substances, and, consequently, there is no passage for the gases, the substance being impervious alike to water and gas. Hence, when this material is employed as tamping, the forces act only upon the lower surface, friction takes place among the particles, and the requisite degree of resistance is produced. By reason of its possession of this property, clay is generally used as the tamping material.

In rock blasting, it is usual to prepare the clay beforehand, and this practice is conducive both to effective results and to rapidity of tamping. The latter consideration is an important one, inasmuch as the operation, as commonly performed, requires a good deal of time. To prepare these pellets of clay, a lump is taken and rolled between the palms of the hands until it has assumed the form of a sausage, from three to four inches in length, and of the diameter of the bore-hole. These pellets are then baked until they are thoroughly dry, when they are ready for use. In making them up to the requisite diameter, a little excess should be allowed for shrinkage, since it is essential that they fit tightly into the hole. When the charge has been put in, and covered with a wad of hay, or a handful of sand or rubbish, one of these pellets is inserted and pushed home with a wooden rammer. Considerable pressure should be applied to make the clay fill the hole completely, but blows should be avoided. A second pellet is then pushed down in the same way, and the operations repeated until the whole of the hole is tamped. To consolidate the whole, light blows may be applied to the outer pellet. It will be found advantageous to place an undried pellet immediately above the charge, because the plasticity of such a pellet enables it to fill all the irregularities of the sides of the hole, and to securely seal the passage between the sides and the tamping, along which the gases might otherwise force their way.

In coal blasting, soft shale is always used for tamping, because it is ready at hand, and heavy shots are not required. It may be desirable to call attention here to an erroneous notion prevalent

relative to plastic clay tamping. It is supposed that clay in a moist and plastic state opposes a much less powerful resistance than when dry. This is to some extent true, and the reason appears to be that less friction is produced among the particles when the latter are lubricated with water. The difference of the effects, however, is less than that due to difference in friction. The outsides of the dried pellets become granulated by being forced down in rubbing contact with the sides of the hole, and thus a film of porous material is interposed between the latter and the tamping, through which the gases may force their way. It is to prevent such an occurrence, that the plastic pellet next the charge is recommended. But when the whole of the tamping is of a plastic character, no pulverization occurs, and hence it is that the lessening of the friction is nearly compensated. The plastic clay should be applied in rolled pellets in precisely the same manner as the dried clay, except that no blows should be resorted to. By plasticity, we must be understood to mean only that due to a moderate degree of moisture, such as will allow the clay to yield before considerable pressure without crumbling.

Broken brick constitutes a fairly good tamping material, especially when tempered with a little moisture; but as it is not readily procurable, its application is necessarily limited. The dust and chippings of the excavated rock are largely employed as tamping in quarries. This material, however, has but little to recommend it for the purpose beyond its readiness to hand.

It now remains to consider what means are available for remedying the defect inherent in sand as a tamping material. This constitutes a very important practical question, because if the defect can be removed, sand will form by far the most suitable material whenever the bore-hole has a downward direction. It can be everywhere obtained at a low cost; it may be poured into the hole as readily as water; and its application gives rise to no danger. Two methods of overcoming the difficulty present themselves: one is to employ means of preventing the gases from penetrating the sand; the other, to have recourse to detonation.

The end proposed in the former of these methods may be successfully obtained by means of the plastic clay pellet in the following manner. Immediately above the charge, place a handful of perfectly dry and very fine sand. This may be obtained by sifting, if not otherwise procurable. Upon this sand, force firmly down with a wooden rammer, so as to fill every irregularity, a plastic clay pellet, about four inches in length and of the same diameter as the bore-hole, prepared by rolling between the hands in the manner already described. Above this pellet fill the hole with dry sand; the impervious nature of the clay prevents the gases from reaching the sand, except along the line of junction of the clay with the sides of the hole. As the depth of clay is at the most four inches, an escape of gases along this line may occur in a greater or less degree, according to the greater or less regularity of the hole, and the more or less care with which the pellet is forced down. To prevent this escape is the use of the fine sand beneath. The particles, taken up by the gases, become closely wedged into the interstice, and completely block the passage. Tamped in this way, a resistance is obtained scarcely if at all inferior to that opposed by the most carefully-placed dried clay.

By the employment of a detonator, the defect due to the porous character of sand is not removed, but its influence is greatly diminished. When detonation is produced in an explosive compound, the full force of the elastic gases is developed instantaneously; and it has already been shown that, under such conditions, the resistance occasioned by the presence of any substance in the bore-hole, even the air alone in the case of nitroglycerine, is sufficient to throw the chief portion of the force upon the sides of the hole. Loose sand, therefore, may be successfully employed as

tamping under these conditions, since its inertia will oppose a sufficient resistance to the escape of the gases. But though the rock may be dislodged when light tampings are used with detonation, there can be no doubt that a considerable proportion of the force of the explosion is lost; and hence it will always be advantageous to tamp securely by means of the clay pellet, as already described. The highest degree of economy is to be attained by detonating the charge, and tamping in this manner.

Conditions of Disruption.—Having explained the laws according to which the elastic gases evolved by an explosion act upon the surrounding rock, and described the means by which the forces thus developed are made to bear upon the points desired, it now remains to consider the conditions under which disruption may take place. Suppose a block of unfissured rock detached on all sides, as shown in plan, in Fig. 372, and a bore-hole placed in the centre of this block. If a charge be fired in this position, the lines of rupture will radiate from the centre towards any two, or towards all four of the unsupported faces of the block, because the forces developed will act equally in all directions, and the lines of rupture will be those of least resistance. Evidently this is the most favourable condition possible for the charge, since the rock offers an unsupported face on every side, and it is evident that the line of rupture must reach an unsupported face to allow of dislodgment taking place. Suppose, again, as shown in Fig. 373, the block to be unsupported on three sides only, and the charge placed at *h*. In this case, the lines of rupture may run to any two, or to all three, of the unsupported faces; and hence this will be the next most favourable condition for the action of the charge. The greatest useful effect, however, will be obtained in this case by placing the charge farther back at *h′*, when the lines of rupture must necessarily run to the opposite faces *b c*, and, consequently, the whole of the block will be dislodged. Assume another case, in which the rock is unsupported upon only two sides, as shown in Fig. 374, and the charge placed at *h*. In this case, the lines of rupture must run to each of the unsupported faces *a b*. Thus, it is evident that this condition, though still a favourable one for the good effect of the charge, is inferior to the preceding. As rock is never homogeneous in composition or uniform in texture, the lines of rupture, which, as before remarked, will be those of least resistance, may reach the faces at any point, as at *m n*, *m′ n′*, or any point intermediate between these. But it will be seen that the useful effect will be greatest when these lines, radiating from the charge, make an angle with each other of 180°, or, in other words, run in directly contrary directions, and that the useful effect diminishes with the angle made by these lines of rupture. Suppose, again, the rock to be unsupported upon one side only, as shown in Fig. 375, and the charge placed at *h*. In this case, the lines of rupture must run to the face *a*, and the condition must therefore be considered an unfavourable one. As, in the preceding case, the useful effect will depend upon the angle made by the lines of rupture *h m* and *h n*, which angle may be very small, and which must necessarily be much less than 180°. A greater effect may be obtained under this condition by firing several charges simultaneously. If, for example, we have two charges placed, one at *h*, and the other at *h′*, and fired successively, the lines of rupture will run in or near the directions *h m*, *h n*, *h′ n′*, *h′ n′*, and the portion of rock dislodged will be *m h n h′ n′*. But if these two charges be fired simultaneously, the lines of rupture will be *h m*, *h o*, *h′ o*, *h′ n′*, and the mass of rock dislodged will be *m h h′ n′*. Simultaneous firing is in this way productive of a greatly increased useful effect in numerous cases, and the mining engineer, and the quarryman especially, will do well to direct their attention to this source of economy. There is yet another case to be considered, in which the conditions are still

more unfavourable. Suppose two unsupported faces at right angles to each other, and the charge placed at h, as shown in Fig. 376. In this case, the lines of rupture will run to each of the two unsupported faces; but as these lines must necessarily make a very small angle with each other—for the length of the lines increases rapidly with the angle—the useful effect will be less than in the last case. It follows, therefore, that this is the most unfavourable condition possible, and as such it should be avoided in practice.

In the foregoing considerations, the holes have been assumed to be vertical, and for this reason the unsupported face which is perpendicular to the hole, that is, the face into which the hole is bored, has been neglected. For it is evident that, under the conditions assumed, the lines of rupture cannot reach this face, which, therefore, has practically no existence. Suppose, for example, a bore-hole placed at h, in Fig. 377, and the rock to be supported upon every side except that at right angles to the hole. The forces acting perpendicularly to the direction of the bore-hole are opposed on all sides by an infinite resistance, and consequently the line of the hole becomes that of least resistance. Hence, in this case, either the tamping will be blown out, or, if the forces developed are unequal to the work, no effect will be produced beyond a slight enlargement of the hole at the base. This, however, is a case of frequent occurrence in practice, and it becomes necessary to adopt measures for making this unsupported face available. Evidently this object can be attained only by so directing the bore-hole that a line perpendicular to it may reach the face; that is, the line of the bore-hole must make with the unsupported face an angle less than 90°. This direction of the bore-hole is shown in Fig. 378, which may be regarded as a sectional elevation of Fig. 377. In this case, the lines of rupture, which will run similarly to those produced in the case shown in Fig. 375, will reach the unsupported face at b, and the length of these lines, and consequently the depth of the excavation, for a given length of bore-hole, will depend upon the angle which the latter makes with the face. This mode of rendering a single exposed surface available is called "angling the holes," and it is generally resorted to in shaft-sinking and driving headings. The conditions involved in "angling" are favourable to the action of strong explosives.

To show how these principles are applied in practice, we will take a typical case of a heading, 7 feet by 9 feet, as shown in Fig. 379. In this case, we have at starting only one exposed face, which is perpendicular to the direction of the driving. Hence it is evident that we shall have to proceed by angling the holes. We might begin in any part of the exposed face; but, as it will hereafter appear, the most favourable position is the centre. We therefore begin at this point by boring the series of holes, numbered 1 on the drawings. These holes are angled towards each other; that is, the two sets of three holes vertically above each other converge in the direction of their lower ends, as shown in the sectional plan. In this instance we have assumed six holes as necessary and sufficient. But it is obvious that the number of holes, as well as their distance apart horizontally, will be determined by their depth, the tenacity of the rock, and the strength of the explosive used. When these holes are fired, a wedge-shaped portion of the rock will be forced out, and this result will be more effectually and certainly obtained if the charges be fixed simultaneously. The removal of this portion of the rock is called "taking out the key." The effect of removing this key is to leave the surrounding rock unsupported on the side towards the centre; that is, another exposed face is formed at right angles, or nearly at right angles, to the first.

Having thus unkeyed the rock by the removal of this portion from the centre, it will evidently be unnecessary, except for convenience, to angle any more of the shot-holes. The second series

therefore (numbered 2 on the drawings) may be bored perpendicularly to the face of the heading. When this series is fired, the lines of rupture will all run to the unsupported face in the centre, and from hole to hole, if the shots be fired simultaneously, and the annular portion of rock included between the dotted lines 1 and 2 will be removed. If the shots be fired successively, the first will act under the condition of one unsupported face, as illustrated in Fig. 375; but as another unsupported face will be formed by the removal of the rock in front of this charge, the succeeding shots will be subject to the more favourable condition represented in Fig. 374. The firing of this second series of shots still leaves the surrounding rock unsupported towards the centre, and consequently the same conditions will exist for the third series (numbered 3 on the drawings), the firing of which series will complete the excavation. The longitudinal sectional elevations, given in the drawings, show clearly the position of the charges relatively to the unsupported faces of the rock.

It may be remarked here that, owing to the want of homogeneity in the rock, and to the existence of joints and fissures, in practice, the outer line of rupture will not run so regularly as indicated, in this assumed case, by the dotted lines. This circumstance will influence the position of the holes in the next series, and furnish an opportunity for the exercise of judgment on the part of the blaster.

There exist also other circumstances which will influence the position and the number of the holes in a very important degree, and which therefore must be taken fully into account at every advance. One of these is the irregularity of the face of the excavation. Instead of forming an unbroken plane at right angles to the direction of the heading or the shaft, this face is broken up by projecting masses and more or less deep depressions. Obviously these protuberances and cavities will influence, in no inconsiderable degree, the lines of least resistance; the latter being lengthened or shortened, or changed in direction by the presence of the former, which give existence to unsupported faces to which the lines may radiate. These conditions must in every case be taken into account when determining the best position for the bore-hole. Of yet greater importance is the existence of joint planes and bedding planes. It will be evident, from a consideration of the nature and mode of occurrence of these planes as described in the first chapter of this work, that they may constitute unsupported faces to which the lines of rupture may run. A bed of rock may be, and frequently is, cut up by these planes into detached blocks of greater or less dimensions, according to the more or less perfect development of the different sets. Hence it becomes necessary, in determining a suitable position for the blasting charge, to consider such planes as unsupported faces, and to ascertain the direction and the length of the lines of least resistance under such conditions. If a charge be placed in close proximity to one of these planes, not only may the lines of rupture run in unforeseen directions, but the greater part of the force of the explosion will be lost by the escape of the gases along the plane. The same loss of force may be occasioned by the presence of a cavity, such as are of frequent occurrence in cellular or vughy rock. When the joint planes are fully developed, their existence can be ascertained by inspection; but when their development is imperfect, there may be considerable difficulty in discovering them. In such cases the rock should be carefully inspected, and sounded with a hammer or pick. When a cavity is bored into, it should be rammed full of clay, and the boring continued through the clay; or if sufficient depth has been obtained, the charge may be placed upon the clay, which will prevent the wasteful dissipation of the gases. As none of the afore-mentioned circumstances recur under precisely similar conditions, no general rules of much service can be laid down: they are matters upon which the blaster must be left to use his own

judgment, and to do this effectively, it is obviously necessary that he possess some knowledge of the materials with which he deals.

A somewhat different mode of unkeying the face is occasionally adopted when the nitroglycerine compounds are employed as the explosive substance. In such cases, instead of angling the holes in the centre of the face, these are bored, three or four in number, close together. When fired with a charge of the strong explosive, the thin partitions of the rock between the holes, and the rock immediately surrounding these to a slight depth, are crushed to dust by the force of the explosion, leaving a large hole in the centre of the face, to serve as the cavity caused by the removal of the key in the former case. The relatively small diameter of the hole, however, affords a less extent of unsupported face than the cavity, and for this reason, as well as that of the small useful effect produced by these first charges, the method must be considered as wasteful of explosive material. The only justification for its adoption is to be found in the increased convenience of execution afforded by the perpendicular direction of the holes, in certain circumstances, when machine drills are used.

Economical Considerations.—Besides the important economical considerations involved in the foregoing, there are others which claim notice. Foremost among these is the question whether, for a given effect, it is better to augment or to diminish the individual importance of the shots; that is, whether it is better to diminish the number of the holes and to increase their diameter, or to diminish the diameter and to increase the number. It may be readily shown, mathematically, and the results are confirmed by experience, that there is an important gain in reducing the diameter of the bore-holes to the lowest limit allowed by the strength of the explosive and in increasing their depth. The gain is in the direction of a great saving of labour and a no less considerable saving of explosive material. Hence we again see the advantage of strength in the explosive employed, and the necessity of having recourse to deep holes in order to obtain the full benefit of that advantage.

It has been proposed to increase the useful effect of the charge by mixing with the explosive some inert substance, for the purpose of making the charge extend farther up the bore-hole. It is believed that by thus distributing the force over a larger area, a better effect may be obtained. Within certain narrow limits, this is true. In the case of dynamite, for example, the addition of 25 per cent. of kieselguhr does not diminish the useful effect of the charge in a corresponding degree. Hence the fact that a pound of dynamite, by reason of this wider distribution, will produce nearly the same useful effect in rock as the same weight of nitroglycerine. But it must be borne in mind that, in consequence of the greater surface to which the gases are exposed, and the presence of the silica in the charge, there is a greater loss of heat. To obtain this wider distribution of force, which, in many cases, leads to a greater useful effect, it has been proposed to mix sawdust with the gunpowder employed in blasting rock. The expedient was tried on an extensive scale in Germany, with the result of a notable economy of powder. A further investigation of the matter, however, showed this result to be due to the excessive quantity employed when applied in an unmixed state. The workmen had been accustomed to follow, in every case, the common rule of charging the hole to a height equal to one-third of its length, and hence it arose that, when the powder was mixed with a large proportion of gunpowder, there was still sufficient force to dislodge the rock. To mix an inert substance with an explosive compound is to renounce the advantages of strength. In the case of the very strong explosive nitroglycerine, the admixture of 25 per cent. of kieselguhr, which otherwise serves a useful purpose, is comparatively unimportant. But it is folly to apply the same expedient to gun-

powder for no other purpose than to economize material. The addition of sawdust, besides exposing a larger cooling surface to the heated gases, causes a slow combustion, and the only positive gain to be hoped for from this source is a greatly increased quantity of smoke.

The simultaneous firing of shots offers several important advantages. It has already been shown how one charge assists another under such a condition, and in what way the line of rupture is affected by it. It must be understood, however, that to produce these effects, perfect simultaneity is necessary. If the shots be fired successively, no matter how rapidly, each will act independently of the others. Thus simultaneity of discharge can be obtained only through the medium of electricity, and hence it becomes important to simplify the means by which electricity may be applied to blasting purposes. There can be no doubt that this mode of firing is destined to come into general use, and, with machine drills, to modify, in no inconsiderable degree, the operations involved in rock excavation. Another advantage of simultaneous firing lies in the fact that less delay is occasioned in waiting for the explosion of the charges. Where a large number of workmen are employed, this delay may be a matter of considerable importance.

THE OPERATIONS OF BLASTING.—When the positions and the directions of the shot-holes have been determined, the operations of blasting are begun by striking a few light blows with a pick upon the spot from which the hole is to start, for the purpose of preparing the surface to receive the drill. In some cases, this preliminary operation will not be needed, but generally some preparation is desirable, especially if the surface is smooth and the hole is to be bored at an angle. As an illustration, we will suppose the case of a vertical hole, as required in shaft-sinking. In this case, the boring will be double-handed, and the set of tools needed will be that described in a former section.

Boring.—When the surface has been prepared by the pick, one man sits down, and placing the shortest drill between his knees, holds it vertically in both hands. The other man, who stands opposite, if possible, then strikes the drill upon the head with the sledge, lightly at first, but more heavily when the tool has fairly entered the rock. The man who is holding the drill raises it slightly after each blow, and turns it partially round, the degree of turn usually given being about one-tenth of a revolution. By this means the hole is kept circular in section, and the accuracy of this form will be dependent upon the regularity and uniformity of the motion imparted to the tool. To keep the latter cool, and to convert the dust and chippings into sludge, the hole is kept partially filled with water. The influence of water upon the rapidity of boring was shown in a former section. To prevent the water from spurting out at each stroke and splashing the man who is holding the drill, a kind of leather washer is placed upon the drill immediately above the hole, or a band of straw is tied round it in that situation. When the hole has become too deep for the short drill, the next length is substituted for it, which is in its turn replaced by the third or longest drill, as the depth becomes greater. Each drill, on the completion of the length of hole for which it is intended, is sent away to be resharpened. In very hard rock the drills may require to be frequently changed, a circumstance that renders it necessary to have several of the same length at hand. The depth of blasting holes varies from 2 feet to 10 feet, according to the nature of the rock, the character of the excavation, and the strength of the explosive to be used. In shafts and headings, the depth varies generally between 2 feet 6 inches and 4 feet, a common depth being 3 feet.

The débris accumulating at the bottom of the hole must be removed from time to time, to keep the rock exposed to the edge of the drill. The removal of this sludge is effected by means of the tool

called a scraper, described in a former section. If the sludge is in too liquid a state to allow of its ready removal by this means, a few handfuls of dust are thrown in to render the mass more viscous. The importance of keeping the bore-hole clear of sludge, and of shortening the time expended in using the scraper, has led, in some instances, to the adoption of means for rendering the sludge sufficiently viscous to adhere to the drill. When in this state, the sludge accumulates around the tool rather than beneath it, the fresh portions formed pushing the mass upward till it forms a thick coating around the tool throughout a length of several inches. When the tool is withdrawn from the hole, this mass of débris is withdrawn with it, and by this means the use of the scraper is rendered wholly unnecessary. This mode of clearing the hole is commonly adopted by the Hartz miners, who employ slaked lime for this purpose. This lime, which they procure for themselves at their own expense, they reduce to the consistency of thick paste by the addition of water, and they store it, covered with water, in a small tin box, which they carry with them to their work. To use this paste, they take a piece about the size of a walnut, dilute it with water, and pour it into the bore-hole. This lime paste is, for the purpose intended, very effective in friable rock, especially those of a granular structure, as sandstone. As the grains of sand resulting from the trituration of such rocks have no more tendency to adhere to each other than to the tool, each of them becomes covered with a coating of lime, which causes them to agglutinate into a viscous mass, possessing a sufficiently adhesive quality to enable it to cling to the tool in the manner described.

When the hole has reached the required depth, it is prepared for the reception of the charge, if gunpowder is used, by removing the moisture from the bottom and sides. This is effected by means of a piece of tow, rag, or a wisp of hay passed through the eye of the scraper, or twisted round it, and forced slowly up and down the hole, so as to absorb the moisture from the face of the rock. When water enters the hole through crevices, it may be stopped back by claying the hole by means of the instrument called a "bull." Also, if water is likely to flow into the hole from above, a little dam of clay must be made round it to keep out the water. The labour of drying the bore-hole may be saved by the use of greased paper cartridges, and even that of claying may be rendered unnecessary by the use of cartridges of a perfectly water-tight character. It is commonly objected against the use of cartridges that they occasion a loss of the explosive force, by leaving empty spaces between the case and the sides of the hole, where irregularities exist in the latter. For it is a well-ascertained fact that the existence of such spaces is the cause of a notable decrease of useful effect. To this objection, there are several answers. In the first place, it may be replied that the loss of force is, from other causes, greater when the cartridge is not employed. In the dryest hole, the rock contains a very considerable degree of moisture. When the powder is put in loose, the grains, which are very greedy of water, are in contact with the sides of the hole during the time of tamping and the burning of the fuse; and the necessary consequence of this prolonged contact is a weakening of the charge, due to the imbibition of moisture from the rock by the grains of powder in close proximity to it. For it must be borne in mind that this imbibition or absorption will extend into the charge to a depth of several grains from the outside. When a paper covering is used this injury cannot occur. Again, it may be urged in favour of the use of the cartridge that if the workmen apply a moderate degree of skill and care, such as should be required by every man in charge of blasters, the irregularities of the hole will be trifling, and consequently the empty spaces will exert but little influence. But a more cogent argument lies in the fact that such spaces may be easily filled up. If a handful of dry and very fine sand be poured in upon the cartridge, the grains will

enter, some at once, and some during the process of tamping, into the interstices, and tightly wedge the cartridge into the hole. It does not, therefore, appear, either that the merits claimed for loose charging, or that the objections urged against the use of the cartridge, rest upon a very solid foundation; and when it is borne in mind that the cartridge, besides the advantages already mentioned, offers an effectual check against the employment of powder in wasteful quantities, the superiority of that mode of charging must be acknowledged. As a general rule, therefore, it may be laid down that gunpowder should always be used in cartridges.

Charging.—When the hole is ready to receive the charge, the latter must be inserted in a manner and by means suitable to the nature of the explosive compound. If this compound is gunpowder, and it is to be employed loose, the requisite quantity is poured down the hole, care being taken to prevent the grains from lodging against the sides of the hole. This precaution is important, since not only is the force of the grains so lodged lost, but they may be the cause of a premature explosion. As it is impossible to prevent this occurrence when the holes are inclined, and difficult when they are vertical, it becomes necessary to have recourse to a tin tube, which should be covered to prevent accidents. This tube is rested upon the bottom of the hole, and the powder poured in at the upper end; when the tube is raised, the powder is left at the bottom of the hole. In horizontal holes, the powder is put in by means of a wooden spoon. It will be obvious that in holes that are inclined upwards, the powder cannot be inserted loose. This is a serious defect of the loose-charge system. The safety fuse is then dropped down, and its end forced slightly into the powder. If it be required to fire the charge from the bottom, in order to obtain a better effect, the safety fuse must be put in before the powder. A wisp of hay, a piece of paper, or some other substance having been put in above the powder, to separate and protect it from the tamping, the fuse is led up against the side of the hole and the tamping put in. When the charge is enclosed in a cartridge, the end of the latter, if of paper, is opened, and the fuse inserted in the powder; the paper of the cartridge is then bound to the fuse by a piece of string. If the cartridge is a waterproof one, the fuse is inserted into the hole in the end, left for that purpose, and a piece of tallow laid on to keep out the water. The cartridge is then inserted into the bore-hole, and forced to the bottom with a wooden rammer; and the fuse having been laid against the side of the hole, as in the preceding case, the tamping is put in. If the charge is to be detonated, the fuse is inserted into the cap of the detonator, and the open end of the cap pressed into firm contact with the fuse by means of a pair of nippers. The detonator is then inserted into the cartridge, and the paper of the latter tied up to the fuse with a piece of string; the cartridge is then placed in the hole. When the charge is loose, the detonator is forced into it, or better, if the fuse is good, placed at the bottom of the hole, before the powder is put in.

When dynamite is used, one or more of the ordinary cartridges, according to the charge required, are inserted into the bore-hole, and each cartridge forced home separately with a wooden rammer. A moderate degree of force should be applied, in order to put the plastic material everywhere into contact with the rock. A safety fuse is then cut clean, and inserted into a detonator cap down to the fulminate; and the cap is fixed to the fuse by pressing the open end into firm contact with the latter. This closing of the cap is important, as it not only prevents the withdrawal of the fuse, but it retains the gases of the fulminate when fired. When water tamping is to be used, grease, tar, or white lead must be applied to the junction of the cap with the fuse. A primer cartridge, that is, a small dynamite cartridge designed to explode the charge, is next opened at one end, and the detonator cap,

with the fuse attached, inserted into the dynamite to a depth of about three-fourths of its length, and the paper of the cartridge is firmly tied to the cap and to the fuse with string. The primer, with the detonator and fuse attached in this manner, is then dropped down upon the charge in the bore-hole, and loose sand or water poured in as tamping, the fuse being led up against the side of the hole, as in the former cases. When the holes have been loaded in the manner described, the charges, whether of gunpowder or of dynamite, are ready for firing as soon as the tamping has been put in.

The operation of tamping was fully described when treating of the principles of blasting.

Firing.—When all the holes bored have been loaded in this way, or as many of them as it is desirable to fire at one time, preparation is made for firing them. The first consideration is the safety of those employed, and to ensure this, an unmistakable signal must be given for all in the immediate vicinity to withdraw. When the man to whom is entrusted the duty of firing the blasts has clearly ascertained that all are under shelter, he assures himself that his own way of retreat is clear. If, for example, he is at the bottom of a shaft he calls to those above, in order to learn whether they are ready to raise him, and waits until he receives a reply. When this reply has been given, he lights the ends of the fuses, and shouts to be hauled up; or if in any other situation than a shaft, he retires to a place of safety. Here he awaits the explosion, and carefully counts the reports as they occur. After all the shots have exploded, a short time is allowed for the ventilation to clear away the smoke and fumes, and then the workmen return to remove the dislodged rock. If one of the shots has failed to explode, at least ten minutes should be allowed to elapse before returning to the place, for it is easy to conceive how many causes may operate to delay the combustion of the fuse. Fifteen minutes is not too long a time to wait in such a case, and a regulation to that effect should be made and strictly enforced. When it has been clearly ascertained that the shot has failed, the men may be permitted to return. But in no case should they be allowed to bore out the tamping for the purpose of inserting another fuse. Numerous fatal accidents have resulted from this proceeding. The unexploded charge should be left untouched, and a fresh hole bored to dislodge the rock. Thus it is evident that careful loading is conducive to economy of time, since a misfire causes a serious delay. In headings, manholes are provided as places of retreat for the blasters while awaiting the explosion; these manholes are small excavations made at right angles to the sides of the heading. Sometimes it is necessary to erect a shield of timbers in the heading, for the protection of the men; such a shield is very frequently needed to protect the machine drills from the effects of the blast. In Belgium, it is a common practice to provide manholes in the sides of a shaft for the retreat of the blasters; these holes are called *caponnières*. Instead of caponnières, a hollow iron cylinder is sometimes used as a protection to the workmen. This cylinder is suspended in the shaft at a height of a few yards from the bottom, and is lowered as the sinking proceeds. The men climb into the cylinder to await the explosion of the shots.

On returning to the working face, the workmen remove the dislodged rock, and break down every block that has been sufficiently loosened. For this purpose they employ picks, wedges and sledges, and crowbars. And not until every such block has been removed do they resume the boring for the second blast. To facilitate the removal of the rock dislodged by the shots, iron plates are not unfrequently laid in front of the face in a heading. The rock falling upon these plates is removed as quickly as possible, to allow the boring for the succeeding blast to commence. It is important, in the organization of work of this character, that one gang of workmen should not be kept waiting for the completion of the labour of another.

In the example of blasting under consideration, the holes are vertical, or only slightly inclined from the vertical. But it is evident that the operations to be performed would be similar in the case of horizontal holes, such as are required in headings, the only differences being those due to the altered direction, which will modify, in a manner easily imagined, the mode of holding the drill, and of clearing and loading the hole.

It may be remarked here that, in some places, notably in the Cleveland district, the bore-hole is made triangular in section, rather than circular. This form is preferred on the supposition that it is more favourable to the convenient fracture of blocks of rock. When, however, the action of expanding gases is borne in mind, it is difficult to see how this result can be brought about by such means. The only fact that appears clearly to follow from the adoption of this form is that, under such conditions, the use of gunpowder in cartridges becomes impossible; that is, all the disadvantages of a badly bored hole are incurred, without any apparent compensating gain. If the action of an explosion be carefully considered, and all the conditions of blasting be taken into account, it must be acknowledged that the more truly circular the hole, the more favourable is it for the charge. It is indeed one of the advantages afforded by machine drilling that the holes are bored truly circular.

The foregoing description of the operations involved in blasting apply only to hand drilling. When machine drills are employed, these operations will necessarily differ somewhat in their details from those described, and, in some cases, other methods of procedure will be adopted, more suitable to the requirements of machine labour. It may even be inexpedient to follow the principles which lead to economy of the explosive substance employed, since the more restricted conditions under which machine power can be applied may point to more important gains in other directions. Thus it may be found more conducive to rapidity of execution to determine the position and the direction of the shot-holes rather to satisfy the requirements of the machine, than those of the lines of least resistance; or, at least, these requirements must be allowed to exert a modifying influence in determining those positions and directions. These questions will be considered incidentally in the following section and chapter, where the details of the operations will be fully described; and some proposed systems of applying machine drills to give the greatest useful effect will be explained and illustrated.

CHAPTER IV.—*continued.*

SHAFT-SINKING.

SECTION II.

In the foregoing section, the tools and other mechanical appliances used in the excavation ot rock have been somewhat minutely described, and the principles upon which the use of these means are based fully explained. It has been shown that an accurate and intimate knowledge of such means must precede any attempt to apply them to the important requirements of practice, since the ultimate success of an undertaking, both from engineering and from commercial points of view, is greatly dependent upon the possession of this knowledge by those to whom the execution of the work is entrusted. And attention has been directed to the necessity which has arisen for the substitution of machine for manual power to meet the rapidly growing demands for the produce of the mine, and the altered relations subsisting between capital and labour. It now remains to consider and to describe the various operations involved in the important undertaking which forms the principal subject of the present chapter.

The shaft of a mine constitutes the means of communication between the underground workings and the surface, and as such its importance commends itself at once to the understanding. It would, indeed, be difficult to overrate this importance from whatever point it be viewed. During the process of sinking, the shaft has to pass through all the strata intervening between the surface and the seam to be worked, whatever their nature may be. This nature may be such as to render the operations simple and easy, and they may be such as to render them exceedingly difficult and almost ruinously costly. To the bottom of the shaft, the whole produce of the mine must be brought, and from the mouth, at surface, it must all be conveyed away. Moreover, every particle of this produce has to be drawn up the shaft, and, by the same way, all the material required has to be let down. The same means of communication serves to introduce the air necessary to the ventilation of the workings, and to convey away that which has become unfit for respiration, and through the same passage, the miners employed in extracting the mineral must every day pass. Hence it is obvious that the shaft will claim the most serious attention of the mining engineer, and call for the most careful exercise of his knowledge and judgment.

Designations of Shafts.—Shafts are classed and described according to one of the several uses to which they are put. Thus we have an *engine* shaft, up which the water is pumped, and over which the pumping engine is situate, from which it takes its name. A *winding* or *drawing* shaft, up which the mineral is raised, and in connection with which the winding engine is erected. An *air* shaft, which is sunk to a seam for the purpose of providing ventilation. A *down-cast* shaft, down which the fresh

air passes to the underground workings. And an *up-cast* shaft, up which the fouled and heated air passes from the workings to the surface. In thus designating shafts, or as they are commonly called in the coal districts, "pits," it is not intended to convey an idea of a special and an exclusive use, but rather to direct attention to that particular one of its several uses which relates to the subject in question. Thus, in reference to ventilation, the shafts are spoken of as down-cast and up-cast; and in reference to the extraction of the mineral, or the removal of the infiltering water, as winding or engine shafts. Winding may be, and usually is, carried on through both the down-cast and up-cast shafts, and the pumping may be performed through either.

Number, Form, and Dimensions of Shafts.—It was formerly the practice, in mines of small extent, to sink but one shaft to the seam, on account of the costly character of sinking operations. In such a case, this single shaft had to serve all the purposes indicated in the foregoing paragraph; and to enable it to do this, it was divided into several compartments. One of these compartments was set apart for the pumps, and two others for the winding, while the air was conveyed down one of these and up another, or the two others. This arrangement was, however, a very dangerous one to the lives of those employed, since an accident to the shaft cut off all means of retreat. Under this system many terrible accidents occurred, and at length the Legislature was compelled, in the interests of those employed, to interfere and prohibit the working of a mine with less than two shafts. Two, therefore, is the least number possible. In districts where the seams of coal are accessible at small depths, less effort is made to reduce the number of shafts to the lowest practicable limit. But when great depths have to be attained, the workings are always laid out with this view. In Staffordshire, for example, the shafts are very numerous, and of small diameter, and the winding through these is carried on at a slow speed. In Durham, on the contrary, the shafts are few and of large diameter, and the winding through them is effected at a very high speed. In all cases, however, economy requires that this latter system should be followed; that is, that the number of the shafts should be reduced to the lowest practicable limit; that their dimensions should be sufficient to supply an adequate quantity of air to the workings, and allow the passage of capacious tubs in properly constructed cages; and that the winding should be carried on at a high speed. The actual number of shafts requisite can be determined only by the conditions of the case.

The form of the shaft varies considerably. Thus we have, in England, shafts circular or elliptical in section in the coal districts, and rectangular in the metalliferous districts. On the Continent, the rectangular and polygonal forms, as well as the circular, are adopted for coal shafts. These various forms of shafts are by no means due to caprice or to custom, but are determined by several conditions. The rectangular section occasions the least waste of space, and the circular the greatest. This consideration, however, does not influence the choice in any very great degree. The determining conditions are, mainly, the strength of the rock passed through and the material available for supporting the sides. When the sinking is through plastic clay or running sand, for example, the pressure upon the lining of the shaft is very great, and this pressure is exerted nearly equally in all directions. To resist this pressure, the circular form is the most suitable, and it is for this reason that it has been adopted whenever the rock is of a weak and unstable character. Another reason tending to confirm the choice of the circular form under such conditions, in localities where stone and brick are the only materials available for lining, is that that form lends itself most readily to the nature of those materials. On the contrary, where wood is abundant, as in some of the Continental and American coal fields, and is therefore preferred to masonry, as a lining to the shafts,

the circular form is an impossible one, and the rectangular the most suitable. Hence it arises that, while in England the circular and elliptical forms are exclusively adopted for coal shafts, the rectangular and polygonal forms are resorted to in other countries. Similar conditions prevail in Cornwall, where the rectangular shaft is almost exclusively used, and in other metal-mining districts of England. The rocks of those districts, being of a strong character, need but little support, and this support is given by timbering. It may be remarked that rectangular shafts are never made square, and that the length varies from about once and a half to three times the breadth.

Shafts also vary widely in their dimensions. But the tendency of the present time is in the direction of large diameters, which tendency is, as we have already stated, in accordance with the requirements of economy. Circular shafts should never be less than 9 feet in diameter in the clear, and they may be as much as 16 feet in diameter. In some instances, both in England and on the Continent, elliptical shafts have been sunk, the diameters of which are as much as 18 feet and 20 feet. In France and Belgium, the diameter of circular shafts rarely exceeds 10 feet. Yet there, as in England, the tendency is to increase the dimensions. The up-cast should, for reasons that will be hereafter explained, possess a larger diameter than the down-cast. When the section is rectangular, the dimensions are very various. In France and Belgium, they are commonly between 4 and 6 feet in breadth, by from 9 to 16 in length. In the Hartz mountains, the dimensions are usually great; many shafts are 10 feet in breadth by 26 feet in length. These dimensions are, however, outside the timbering. In the clear, these shafts would be about 8 feet in breadth by 23 feet in length. In America, where the shafts are usually inclined, and partake more of the character of day-levels than shafts proper, the dimensions adopted are often very large. Of course, the dimensions of a shaft must be determined in accordance with the degree of pressure likely to be thrown upon the walls. Thus in ground of a very unstable character, even a strongly walled shaft of a circular section may not exceed a moderate diameter.

Position of the Shaft.—When the requisite evidence concerning the dip, thickness, and regularity of the seam has been obtained by boring, or by any other reliable means, the position of the sinking may be determined. The selection of the most favourable position for the shafts is, perhaps, the most important duty that the mining engineer is called upon to perform. It is one that requires extensive knowledge and sound judgment, and entails an amount of responsibility that is not to be accepted lightly. An error of judgment in an undertaking of this nature may lead to very serious consequences, which can afterwards be neither remedied nor mitigated. It behoves the engineer, therefore, who is called in to advise on such a matter, to exercise the utmost caution, to obtain complete evidence concerning all the facts of the case, and to weigh this evidence carefully before arriving at a decision, which cannot be revoked.

There will be in every case two sets of conditions which will determine the position of the shaft, and, in many cases, there will be a third set to influence the question in a considerable degree. The first set of determining conditions to be taken into consideration are those which relate to the seam itself, and the workings in that seam. Foremost among these are the dip of the strata, the degree of their inclination, the quantity of water likely to be met with, and the character of the seam as a source of explosive gas. These are questions determinable by means of surveys, borings, and inquiries in neighbouring mines, and they must be ascertained for every particular case. The other conditions of this set relate to the proposed method of working the seam, and the general plan of the workings. It must always be borne in mind that the whole of the produce will have to

be brought to the bottom of the shaft, and that, therefore, it is desirable to place the shaft in a position favourable to the conveyance thither of that produce. Also, as it is requisite for the sake of economy to reduce the number of shafts to the lowest possible limit, they should be so situate as to command the most extensive area in the field to be worked out. The extremities of the area apportioned to a shaft should not, however, be so distant as to render the conveyance of the produce of the seam difficult, since this would frustrate the object of diminishing the number of shafts. Other circumstances will also weigh in an important degree, such as the existence of faults, the vicinity of old workings, or the presence of any of the other numerous obstacles that are likely to occur.

Among the most important of these underground conditions are those which relate to the gravitation of the water and of the loaded tubs towards the pumping and the winding shafts. These questions will be considered in a subsequent chapter.

The second set of determining conditions relates to the circumstances existing at surface. These are of very great importance; in all cases, their influence will modify the decision arrived at from a consideration of the first set, and not unfrequently it will preponderate, and determine alone the choice of the position; that is, the position chosen in accordance with the surface conditions may be unfavourable to the conditions prevailing underground. Of course, the latter cannot be ignored, and it must be borne in mind that the degree to which they may be set aside will be entirely dependent upon their importance. The determining conditions prevailing at surface relate to the disposal of the several products of the mine, namely, the coal, the rubbish, and the water. The first of these, which is the useful product, and which will be raised in by far the largest quantities, will certainly claim the chief consideration, but the removal of the rubbish and the water will influence the choice in some degree. The coal will have to be conveyed to the nearest highway, canal, or railway; and it is obvious that the situation of the coal-field relatively to these, the surface configuration of the locality, and the existence of natural and artificial obstacles, will exert a weighty determinative influence on the position of the shaft, between which and the afore-mentioned means of communication a constant, suitable, and sufficient connection must be kept up. Generally, this connection will be made by tramway, and the foregoing circumstances will, therefore, have to be considered relatively to the requirements of such means of transport. Sometimes no railway may exist, but it may be intended to construct a branch to the colliery from a line a few miles distant. This, however, amounts to nothing more than increasing the importance of the tramway. In all cases, advantage should be taken of gravitation to run the loaded trucks away from the shaft in order to save an expenditure of costly power. But to do this, a position must be chosen for the shaft sufficiently elevated above the railway or the canal, and to make this position accord with the other determining conditions above and below ground is the problem that the engineer is required to solve. It will thus be apparent that the problem is a difficult one, and its solution will demand the exercise of judgment and of skill. It will also be evident that the fulfilment of this condition will be favourable to the removal of the rubbish derived from the excavation of the shaft, and to the discharge of the water, whether the discharge take place from the surface, or through an offtake.

The third set of conditions which may occasionally supervene to limit the influence of the first and the second, relates to the character of the strata through which the shaft is to be sunk. In some localities, it may happen that quicksands or drift of an unstable nature will have to be passed through, and it then becomes a question of passing through these beds in the most favourable part. In such a case as this, borings afford valuable evidence, and should be deemed indispensable. The

very costly character of sinkings through water-bearing and unstable beds gives great importance to those conditions, and frequently renders them paramount. Numerous instances might be cited in which altogether unfavourable positions have been selected for the shafts solely for the purpose of escaping the difficulties that would otherwise be encountered in traversing such beds.

The foregoing remarks on the position of the shaft, or, as it is commonly expressed, the spot for the winning, are necessarily of a general character. It is impossible to give definite directions concerning circumstances that never exist under the same conditions in any two localities. Instructions that might be profitably followed in one case, would be only partially applicable to another, and to give such instructions would be rather to mislead than to guide. It is, however, desirable to point out what the determining circumstances may be, and to indicate their relative importance. The means by which the end desired may be obtained, in assigning to each condition the influence due to its importance, must be left for individual skill to apply.

It has been already remarked that the minimum number of shafts to every colliery is two. The legislature provides that these shall be separated from each other by not less than 10 feet of natural strata; but beyond this limitation they may be placed at any distance apart, and in any position relatively to each other that best fulfils the foregoing conditions and is most suitable to the system according to which the workings are to be laid out. Sometimes it is found convenient to separate the shafts by long distances; but generally they are placed only a few yards apart. By bringing the shafts near together, the important advantage is gained of concentrating the points of delivery, and the machinery required at those points, upon one spot at surface. Other advantages will be rendered apparent in describing the operations of sinking, and the modes of laying out the underground workings. The position of the shafts relatively to each other and to the dip of the strata, will also be determined by those considerations, which will form the subject of the following chapter.

THE OPERATIONS OF SINKING.—In the operations of sinking, as in those of boring, rapidity of execution may be deemed generally essential to the success of the undertaking. It is, therefore, important that every means should be employed to facilitate the several operations involved, and due precautions taken to prevent delays. To this end, the preliminary arrangements should be carefully considered and completely carried out. All the tools and other appliances required should be suitable in character, and of the best design and quality, and means should be always ready at hand for keeping these in a proper condition, and of promptly repairing them in case of damage. This foresight should be exercised throughout the whole of the preliminary arrangements and labour undertaken previously to commencing the actual work of sinking. Every difficulty that may be encountered should be fully provided against, so that valuable time may not be lost in devising and searching for the necessary means when the difficulty has presented itself. Such delays increase the difficulties immensely, and may render the cost of overcoming them ruinously great. Indeed, it may be said that a sinking well considered and fully provided for, is a sinking half accomplished, and, therefore, no pains and no expense should be spared in the measures taken to insure the attainment of this object. It will also be necessary, during the progress of the work, to see that the advantage thus gained be not lost by neglect. A vigilant supervision must be held necessary from the moment of the commencement of operations to that of their completion, and this supervision should be extended to the minutest and the seemingly most trivial details. When the end to be attained is so important, the smallest matter is not beneath notice. Besides, it should be borne in

mind that a habit of inattention to small matters is very apt to extend itself to others of greater importance.

In order to explain and to describe in an intelligible manner the various operations involved in sinking a shaft, we will assume a pair of circular shafts, one of which is to serve as a down-cast, and the other as an up-cast, the former being 13 feet, and the latter 14 feet in diameter. As the operations in each will be identical in character, it will be sufficient to consider the down-cast alone, merely premising that the two will be sunk simultaneously, and that, consequently, the preliminary arrangements must include provisions for this circumstance. The advantages of sinking both shafts simultaneously are great and obvious. For besides reaching the seam through the two shafts at the same time, whereby the immediate opening out of the underground workings is much facilitated, the water encountered is more easily dealt with, and one provision of tools, machines, and surface erections is sufficient.

The preparatory work consists, as we have seen, in providing the tools and other mechanical appliances, the materials of various kinds, and the buildings that will or may be required in the progress of the sinking. The tools chiefly required will be the picks and sinking shovels already described as suitable for working in rock, the stone-blasting gear, also described and illustrated, and wedges for dislodging jointed or fractured rock, and rock-boring machines, when these are to be employed, together with the air-compressors, and the other appliances and materials to be used with them, as reservoirs, tubing, and repairing tools. Besides these tools for dislodging the rock, there will be required corves or kibbles for raising it to surface. It was formerly the custom to construct these sinking corves of wicker work, well-seasoned hazel being used for this purpose. The capacity of one such corf was about 20 gallons. These corves have, however, been almost entirely superseded by "kibbles" constructed of wooden staves bound together by iron hoops like a small cask, and provided with a handle or with three ears to which chains may be attached, to form a kind of bucket, as shown in Fig. 383. When of small dimensions for well sinking, it is called a sinker's bucket. This form of kibble, which is much used on the Continent, is made to "belly" in the middle to make them sheer off from each other should the ascending and the descending one come into contact. For the same purpose, the edges of the hoops are chamfered off. This is a danger to be carefully avoided, inasmuch as the canting of the loaded kibble pours the contents down upon the sinkers. In England, the sinking kibble is commonly constructed of iron, and in that case its form is very similar to that adopted for the wooden barrel-shaped bucket. The kibble is attached to the rope by a spring hook, shown in Fig. 384, or by the form of hook represented in Fig. 385. The former is the more convenient, and perhaps the safer form. The kibble is raised at first by means of a common windlass with two handles, which, therefore, will have to be provided for that purpose. Besides the foregoing tools, and appliances of a like nature, an ample supply of curbing and planking should be provided for the support of the sides of the shaft. The construction of this curbing and the method of applying it with the planking will be described hereafter.

The surface erections required, besides those of a more important and permanent character, which will be described later, are: a carpenter's shed, a smithy, an office for the master sinker and others in charge of the work; a sinkers' lodge, for drying the sinkers' clothes and other purposes; a shed wherein to store the materials required; and a magazine to contain the explosive substance to be employed. In some cases, cottages will be needed for the sinkers, and other erections may be necessitated by the peculiar circumstances of the case. As nearly the whole of these buildings will

be required to remain as parts of the surface works, their situation relatively to the shaft and to each other should be chosen rather with a view to subsequent convenience than to immediate exigencies. When all of those buildings which will be required during the progress of the sinking have been erected, the engine houses may be commenced, and their construction carried on during the sinking of the shafts, so as to be ready for the reception of the engines as soon as the latter are required. In this way, delay in opening out the workings may be avoided. Generally the winding engines will be situate between the two shafts, so as to draw from both.

Sinking to the Stone Head.—When all the preparatory work has been completed, and everything likely to be required is ready to hand, the operations of sinking will be begun by determining the point that is to be the centre of the shaft, and striking from this centre a circle having a diameter 2 feet greater than that which the shaft is to have when finished. In the case assumed this diameter is to be 13 feet; the circle will therefore be struck with a diameter of 15 feet 6 inches. When this has been done, the excavation of the soil will be commenced with the pick and the shovel. The nature of the operations from this point will depend greatly upon that of the rock to be passed through. In the case under consideration, it will be assumed that the first 15 or 20 yards will pass through moderately strong clay.

The firm rock to be met with after the clay has been passed through is spoken of as the "stone head," and this part of the sinking is described as "sinking to the stone head." As the excavation during this portion of the sinking is through soft rock, the pick and the shovel will be the only tools required, and the sinking will progress with rapidity. The "stuff" will be raised to surface in kibbles by means of the ordinary jack-roll, and tipped, or, in miner's language, "teemed" around the mouth of the shaft. A matter to which attention must be given at the commencement of the excavation, and continued throughout the whole of the sinking, is the preservation of the verticality of the shaft. The axis of a shaft must be kept rigorously vertical throughout its length, the slightest deviation from that direction being attended with evil consequences not easily remedied. In rectangular shafts, each face should form but one vertical plane from top to bottom, and in circular and elliptical shafts, each generating line should be perfectly straight and vertical. This regularity of form must be preserved throughout the subsequent operations of timbering, walling, and tubbing, care being taken to place these supports everywhere in exact accordance with the centre of the shaft. To insure this verticality to the excavation, frequent and careful use must be made of the plumb-line. In rectangular and polygonal shafts, a plumb-line should be suspended in each angle; and in circular and elliptical shafts, at the four extremities of the two diameters crossing each other at right angles, in the former, and at the extremities of the major and minor axes in the latter. If the section is large, lines may be required at other points also, to be determined by the engineer or the master sinker, according to the conditions of the case. These suspended lines will be lowered as the sinking progresses, and from time to time other lines will be dropped, in the same positions, from the surface to near the bottom of the excavation, to check the accuracy of the work done. All irregularities rendered apparent by this plumbing must be carefully removed.

Curbing.—During the sinking to the stone head, however, the sides of the shaft cannot be left without support. There is a tendency in soft rock, as we have seen in deep boring, to swell and to close up the excavation. We have also seen that when this swelling has once begun, its progress is rapid, the motion produced in the rock being an accelerated one. Hence it becomes necessary to prevent the swelling action from setting in, by placing a sufficient support to the

sides of the excavation as the sinking progresses. This support consists, for circular shafts, of rings formed of segments of wood, called "curbs" or "cribs," placed at intervals in the shaft, and backed with deal planking. The curbs should be of oak or elm, and their dimensions should be proportioned to their diameter, and to the degree of pressure likely to be brought upon them.

These dimensions will vary from 4 to 6 inches square. Care should be given to their construction in order to bring the ends of the segments to bear evenly upon each other, and to make the joints radiate truly from the centre. The best mode of forming the joint is that shown in Figs. 386 to 388, in which the ends of two contiguous segments are made to bear against each other in one vertical plane. When jointed in this way, the segments are prepared at surface with the curved wooden fish-pieces or cleats, and sent down the shaft ready to be put together, as shown in the drawing. Another method of jointing the curbs is shown in Fig. 389. The backing deals used with the curbs should be about 1 inch in thickness, and about 6 feet long; if desirable, a greater length, say 9 feet, may be adopted. The first length of backing deals set should, in every case, be 9 feet. It is highly important that there should be always ready at hand a sufficient number of curbs, and an ample supply of the planking required to be used with them.

In the case we have assumed, the curb may be 5 inches square in section, and when put together it should have an inside diameter of 13 feet 9 inches. When the excavation has reached a depth of 6 feet, the first curb is sent down in segments, and put together and placed in position at the bottom. The 9-feet backing deals are then placed vertically behind the curb, their ends passing down to about the middle of the thickness of the latter. If the ground to be supported is very weak, the backing deals must be placed close together; in fairly strong rock, they may be set at small intervals apart. The distance to be allowed between the curbs will be determined by the pressure from the sides of the excavation. If that pressure is very great, the interval should not exceed 2 feet, or in some cases even less than that distance. Instances are on record in which 6 inches could not be exceeded. A common distance, however, is 3 feet, and this might be adopted in the case under consideration. A second curb, therefore, having been sent down, and put together upon the first, is raised to a height of 3 feet above the latter, the height being measured from centre to centre, and supported by a few upright props called punch props. A third curb is then put together upon this second one, and, having been raised 3 feet above it, is supported by props in the same manner as the second. A fourth curb is put in at the top of the backing deals, and supported in the same way as the others. This last curb will thus be situate at the height of 3 feet above the surface of the ground. The object of this elevation is to obtain a height for tipping the stuff drawn from the shaft. The curbs inserted in this manner are next *strung*, or hung together vertically by means of thin deal planks, called on that account "stringing deals." These stringing deals are nailed against the inside of the curb, so as to suspend the latter one from another, and the whole may, if needed, be suspended from balks of timber at surface by means of the stringing deals. Fig. 390 shows a section of the shaft thus supported by curbs and planking.

When the curbing of the excavation has been completed in the manner described, the sinking may be resumed, and continued down another 6 feet. This part of the excavation is not, however, extended to the full diameter; but the sides are kept in a line with the inside of the curbs. This is necessary in order to leave a support for the latter. When the depth of the second 6 feet has been reached, the excavation is shorn out to the full diameter, and a level bed provided for the reception of the next curb. This is sent down in segments, as before, put together, and placed in position at

the bottom. The sides are then shorn out up to the first curb laid, that is, the lowest curb of the first set, and the 6 feet backing deals put in behind this curb and the one just laid. Another curb is sent down, put together upon the bottom one, and raised upon props to a height of 3 feet, that is, midway between the curb last put in, and the lowest of the first set. Upon this curb, props are set to support the one immediately above it, and the stringing deals are nailed on to hang them all together. It is to be remarked here that the whole length of curbing should be slung by means of the stringing deals to balks of timber at surface. This is necessary to prevent the curbing from slipping down when the support is removed by shearing out the sides from under them. The deals may be suspended from the timbers forming the temporary staging required around the mouth of the shaft for convenience in drawing and tipping the rubbish. When the second 6 feet of excavation has been curbed, the sinking will be again resumed, and continued through the third 6 feet, which length will be curbed in the same manner as the preceding. These operations will be repeated until the stone head is reached. In the case under consideration, it is assumed that the clay is of a sufficiently firm character to stand with safety during the excavation of 6 feet in depth. But in weak ground, such a depth may be too great, and in that case the curbing will have to be put in more frequently.

Walling.—When the stone head has been reached, another set of operations has to be performed. The support afforded by the curbing is intended to be only of a temporary character. The continued pressure of the sides of the shaft against this support would, in a short time, cause it to yield, and when the sides have begun to run, the destruction of the shaft is almost inevitable. Hence it becomes necessary to replace the timbering by masonry, and the substitution of the latter for the former should be made as soon and as speedily as possible. In general, however, the walling, as this masonry support is called, cannot be built until a firm rock foundation has been reached, that is, until the sinking has reached the stone head. Thus it is desirable to push on the sinking to this point with all possible speed, in order to escape the danger which always exists, of the timbering giving way before the enormous pressure to which it is exposed. The walling of this portion of the shaft is, therefore, the next labour to be undertaken.

On reaching the stone head the excavation is reduced in diameter, and the sinking is continued until the rock has become sound and strong. When this point has been attained, the sides are shorn back to a greater diameter than the excavation had previously possessed; in the case in question, say to a diameter of 15 feet 9 inches. It is now required to prepare the foundation for another curb of larger dimensions, upon which the walling is to rest, and called on that account the "walling" curb, or sometimes, from the method of fixing it, the "wedging" curb. This curb may be either of metal or of wood. Sound and well-seasoned oak is commonly employed. When iron is used, the curb is open on the inner side. The oak wedging curb will be 13 inches on the bed, as the walling is to be of brick, and 6 inches in depth; its inner diameter will, of course, be that of the shaft, namely, 13 feet. The rock bed upon which this curb is to rest must be carefully levelled, so as to give it an even bearing at all points. Some half-inch fir sheathing is then laid upon this bed, and the curb laid upon the sheathing. Before proceeding to fix the curb, it is important to ascertain that its centre coincides exactly with that of the excavation. When the curb has been placed accurately in position, a backing of fir, about 2 inches thick, is put in vertically between the outside of the curb and the sides of the shaft, and firmly wedged. The wedging must be performed simultaneously at opposite points in the curb, and it must be continued until no more wedges

can be driven in. The greatest care must be exercised during these operations to avoid displacing the centre of the curb. When iron curbs are used, a piece of oak sheathing is placed between the joints; the thickness of this sheathing should diminish from the outside of the curb inwards. As the pressure thrown upon the curb by the wedges tends to lift the former from its bed, this tendency must be counteracted by props set upon the joints of the curb, and abutting against the rock above. To avoid repetition, a detailed description of the operations of wedging, with drawings illustrative of them, is deferred to a later paragraph, in which the method of fixing the wedging curb in a durably water-tight manner for the support of tubbing is treated of.

When the walling curb has been securely fixed, the walling of the shaft may be proceeded with. In most cases, the walling will consist of bricks, which is the cheapest material available, and sufficient for the purpose under all conditions. Frequently these bricks may be made on the spot from the clay necessarily excavated for the surface works. It is essential that the bricks used in the walling be moulded to the form required by the shape and diameter of the shaft. The mortar should be of the best quality and slightly hydraulic in character; and strict supervision should be exercised to ensure good workmanship. In walling through wet strata, quick setting cement will be required.

Sometimes stone masonry is adopted for the walling of a shaft. In such cases the material should be carefully chosen, for the adoption of an unsuitable stone entails constant labour in repairs, and it may endanger the very existence of the shaft. Stone of a schistose structure is rapidly disintegrated by the action of atmospheric agencies, and must, therefore, be held to be quite unsuitable for walling purposes. Sandstone and limestone may be employed; but the former is somewhat difficult to work, and the latter is usually costly to obtain. In stone walling the blocks should be of moderate dimensions, and, as nearly as practicable, uniform in size. Very small blocks involve the use of a large quantity of mortar, which it is important to avoid, and very large blocks are difficult to work and to handle; while the mingling of large and small blocks occasions an unequal distribution of the pressure. Each of the blocks should be tooled upon five of its faces, that which is in contact with the rock being alone left in a rough state. The two side faces should be prepared with special care, to insure a close joint, everywhere coinciding in direction with the radius of the shaft.

Bricks, when properly prepared, constitute a more suitable and a cheaper material for shaft walling than stone. The quality of the bricks, however, is a matter of essential importance. The clay of which they are made should be rich in alumina, and entirely free from lumps of calcareous matter. If the clay is not sufficiently rich in alumina, the bricks will be porous and crumbly; on the other hand, if too rich, they are apt to run during the process of manufacture, and are too smooth to hold well to the mortar; while the presence of lumps of calcareous matter may occasion the destruction of the brick. For these lumps, being converted into lime in the burning, swell, on exposure to moisture, and fracture the brick. If the bricks be insufficiently burned, they will not have that degree of consistency which is necessary to enable them to withstand the pressure to which they will be subjected; if overburned, their surfaces may become vitrified, a circumstance that will greatly diminish the adhesion of the mortar. The defect of over burning is, however, not so great as that of under-burning. The proper degree of burning may be ascertained, either by the colour for a given clay, or by the sound emitted when lightly struck. Fireclay is an excellent material for walling bricks, and in some localities it may be procured nearly as cheaply as ordinary clay. Sometimes this material is employed moulded into blocks to the required form. The dimensions of such blocks may

vary; commonly they are 24 in. × 9 in. × 6 in. Fireclay prepared in this way is somewhat expensive, but it makes a very excellent shaft walling.

As before remarked, it is important that the mortar or the cement used should be of the best quality. The hydraulic character of the material requires that it be used immediately after wetting up, and the quicker its setting property, the shorter should be the interval between its preparation and its application. This is a matter that is commonly neglected, to the great detriment of the substance employed. If, for example, a cement is capable of setting in fifteen minutes, and it be allowed to stand ten minutes before using, it will have partially set, and consequently will have to be broken up before being applied. When this cement has set a second time, it will be found that its strength has undergone a very serious diminution. In all cases, the value of this reduction will be proportionate to the ratio of the time allowed to elapse after wetting and that necessary to complete setting. Another mistake commonly made is to employ an unnecessarily large quantity of mortar in walling. In water-bearing strata this practice is a very pernicious one. It should be obvious on reflection that mortar is less capable of withstanding the action of water than stone or brick, and that consequently the employment of a superfluous quantity of that material must weaken, rather than strengthen, the walling of a shaft against which there is the continual pressure of a considerable, sometimes a great, head of water. What is required is to interpose a thin but perfectly continuous film of the cementing material between two faces in contact; and to do this effectually the mortar should be in a somewhat stiff pasty condition. A common mistake is to apply the mortar too wet. The bricks should be slightly moistened before being laid, to prevent their absorbing the moisture from the mortar.

The thickness of the walling will be, in some degree, determined by the pressure likely to be thrown upon it. Thus, in passing through compact rock, a single brick may be sufficient, the object of the walling in such a case being rather to protect the rock from atmospheric influences, and to prevent the fall of detached portions, than to resist a pressure from the sides. In loose rock of a fairly strong character, such as we have assumed in the example under consideration, a thickness of 13 inches will be required, and will suffice; and in very unstable rock, or where there is a very great pressure of water, 18 inches or more may be necessary. In the assumed example, the wedging curb is designed for a walling of 13 inches.

When the wedging curb has been securely fixed, the walling is commenced upon it, as a foundation, and carried up as rapidly as the exigencies of good workmanship will allow. Until a shaft is walled, it is exposed to the danger of closing in, and therefore no exertion should be spared to complete the walling in the shortest possible time. The labour of walling will have to be performed from a staging or scaffolding, capable of being raised as the work progresses. The staging adopted for this purpose is circular in form, and is commonly known as a "cradle." The cradle is a simple wooden construction, consisting of 2-inch planking nailed upon timbers variously put together. Through these timbers stout bolts with a ring attached are passed, and secured on the underside by means of a nut. From these rings the cradle is suspended, by means of chains attached to two ropes, from two winches at surface, one on each side of the shaft. Later, when the surface arrangements are more complete, the cradle will be suspended by one rope. It is almost needless to remark that, to avoid accidents, this rope must possess a wide margin of strength, and it must undergo frequent and careful inspection. Such a rope should be 10 inches in circumference. The diameter of the cradle should be such as to leave a space of about 4 inches all round between it and

the shaft. This space is necessary to ensure the ventilation of that portion of the shaft which is below the staging. When a seam of coal is near the bottom of the shaft, or has been entered or passed through, this precaution is of the highest importance, and means must be adopted to promote the ventilation of that portion. Sometimes, besides the space around the staging, a hole is provided in the centre of the latter, to allow the gas to pass up; through this hole, the tub dips into the sump. If means of escape be not provided, the gas will accumulate beneath the staging, and then a light inadvertently lowered or accidentally dropped may occasion a disastrous explosion. In spite of the precautions taken to avoid an accident of this nature, the accumulation of gas beneath the staging is one of the most fruitful sources of explosion of firedamp.

As the walling proceeds, the timbering immediately above it will have to be removed, and care must be taken during the removal of this portion not to materially weaken that which is left. If the pressure against the timbering is great, a small portion only of the latter can be taken out at a time, and the remainder must be securely stayed. How much may be removed with safety at one time, the circumstances of the case will determine. The curb immediately below which the timbering has been taken out must be supported by vertical punch props set upon the walling beneath, and sometimes, when the pressure is great, by other props placed horizontally or in an inclined position against the sides of the shaft. These inclined props are called "raking" props. Under some difficult circumstances, it may be necessary to build portions of the timbering into the walling; but this should be avoided wherever possible, as the rotting of the wood endangers the masonry.

The hollow between the walling and the rock must be filled with clay, carefully rammed to form a solid backing, or better, with concrete. This is necessary to distribute the pressure equally over the masonry, and it cannot be neglected without risking the safety of the latter. It is also essential, both to the stability of the work and to the convenience of the operations, that means be provided for getting rid of the water which oozes out from the sides of the shaft, and which would accumulate between the walling and the rock if there were no way of escape for it. Evidently the presence of this water would render it impossible to put in the clay or concrete backing in the solid manner required; and if it were allowed to flow over the last course of masonry, the latter would be injured, and the work greatly impeded. It is, therefore, sought to make it flow away from below, by providing an outlet beneath the lowest course of the walling. For this purpose, either an iron pipe is built into the bottom course, after the manner of the "weeping" holes in retaining walls, or a horizontal hole is bored with an auger in the wedging curb itself, which hole is made to communicate with the space between the walling and the rock, through another vertical hole bored near the outside of the curb and left uncovered by the masonry. The outlet thus provided for the water is kept in communication with the space above the backing by means of a little triangular channel formed by two pieces of board, placed with their front edges against the walling, and two or three inches apart, and with their back edges in contact; or, in some cases, by means of a vertical pipe of small diameter, and pierced with holes, which is lengthened as the walling rises. In putting in the backing, care should be taken to make the upper surface incline towards this outlet for the water. By these means, the water soaking from the sides of the excavation may be conveniently got rid of. When the walling is completed and the sinking recommenced, the outlet may be plugged; or if the quantity of water is considerable, flexible tubing may be affixed to it, to conduct the water down to the sump, and so prevent it from dripping upon the sinkers.

A somewhat similar arrangement is adopted for collecting and conveying away the water that

soaks through the walling. This water, which trickles down the sides of the shaft, is stopped and collected at one of the wedging curbs in the following manner. The first three or four courses of brickwork upon the curbs which are to serve this purpose are inset for the purpose of leaving a portion of the upper surface of the curb exposed, as shown in Fig. 391. In this portion of the curb, a groove is cut, so as to form a channel round the shaft. The water which runs down the face of the walling collects in this channel, and is discharged through a hole, bored obliquely in the curb, as shown by the dotted lines in the figure, into a small pipe, called the "waste pipe," through which it is conveyed, either to the sump or to a tank from which the pump takes its water. Sometimes, instead of using the wedging curb for this purpose, a wooden curb of smaller sectional dimensions is built into the walling at the points desired; such a curb is called a "ring curb," a designation that is also applied to the wedging curb when made to serve the same purpose.

Drawing the Stuff.—The shaft walling is continued up to a convenient height above the surface of the ground; this height may vary from 5 to 15 feet. The object of thus elevating the mouth of the shaft is to obtain a good lead for the removal and the discharge of the stuff raised from the excavation. The first stuff raised after the completion of the walling is tipped around the latter to support it, and the rest is run away to a convenient spot. The manner of terminating the walling and of fitting up the mouth of the shaft varies in different localities, according to the method of receiving the loaded kibbles. In the north of England, a kind of covering or staging of wood is fixed to partially cover the shaft, as shown in Fig 392. To prevent the ascending kibbles from striking against the under side of this staging, deals are nailed diagonally against the edge of the staging and a bunton fixed against the sides of the shaft, as shown in the figure. These deals are called "striking" or "sliding" deals. When the loaded kibble is raised to a height a little above the staging, a tram is run out to the edge upon rails laid down for that purpose, and the kibble is lowered upon it by being drawn over it by hand during the lowering. To prevent the tram from running off the staging into the shaft, a wooden sill of sufficient depth is nailed along the edge. The loaded kibble is then detached from the spring hook, and an empty one, brought up on the tram, substituted for it. As soon as the latter is raised to be lowered into the shaft, the tram with the loaded kibble is run back, and the contents discharged, after which it is again pushed forward with the empty kibble for the next load. To facilitate these operations, the rails should be laid with a slight inclination from the mouth of the shaft. This inclination is also needed to prevent the tram from striking heavily against the sill.

In some other coal districts, the manner of receiving the loaded kibbles and the laying out of the shaft mouth are different. This difference will be best understood from a description of the surface arrangements of a shaft in South Staffordshire, on the estate of the Duke of Sutherland. The walling of this shaft, which was sunk under the direction of Mr. C. Bromley, was carried up to a height of about 15 feet above the surface of the ground, and thick brick walls erected to inclose the shaft, in the manner shown in Fig. 394. An inner wall, contiguous to the shaft, forms with the outer walls a rectangular brick foundation for the head-gear. The walls inclosing the shafts carry balks of timber to form a staging on a level with the top of the pit walling. Upon this staging are laid light tram rails, on which runs a wooden tram or movable platform, shown in Fig. 393. This platform is of sufficiently large dimensions to completely cover the mouth of the shaft, when it is run over the latter. In arrangements of this kind, a rail is laid on each side of the shaft to allow the tram to be run over. As it is essential that the mouth of the shaft should be fenced to prevent

accidents, a suitable fence, shown in the figure, is fixed to one end of the tram platform, and supported upon two small wheels on the opposite side. These wheels run upon rails laid for that purpose. Two posts are fixed vertically into the platform to afford a hold in pushing it backwards and forwards. During the drawing, the fence stands over the mouth of the shaft, as represented in the figure. When the load has been raised a little above the level of the platform, the latter is run forwards completely over the mouth of the shaft. The load is then lowered and deposited upon the platform. When the loaded kibble has been removed from the spring hook, and an empty one attached, the latter is raised, and the platform is then run back with the loaded kibble. At the same time, the fence returns over the mouth of the shaft. This particular arrangement of the platform and fence was designed with a special view to the ready removal of the water raised in tubs from the shaft, and we shall have occasion to refer to it again relatively to this use. But as it represents exactly the method adopted in this and other districts for receiving and removing the rubbish as well as the water drawn from the excavation, we have selected it to serve a double purpose. It is obvious that any varieties of detail may be made to facilitate the running away and the tipping of the stuff raised. The principle of this arrangement is everywhere adopted where that described in the preceding paragraph is not in use.

When the walling has been completed, a strong and convenient head-gear must be erected to continue the drawing of the stuff on the resumption of the sinking beneath the walling. The construction represented in Figs. 396 to 398 will be found sufficient and suitable for the purpose required, a height of 18 or 20 feet being ample for a structure of this provisional character.

In connection with this head-gear, a steam engine will be required to draw the rubbish and the water from the excavation. During the sinking and the walling of this first portion of the shaft, the most important of the surface work will have been pushed forward, such as the erection of the buildings for the reception of the pumping and the winding engines. It was formerly the practice to get these engines in position as soon as possible, in order to apply them to the work of raising the stuff and pumping the water, during the progress of the excavation. For as the depth increases, it becomes important that these operations should be rapidly performed. Since, however, the introduction of the winding engine of the locomotive type of construction, the more powerful engines destined to the ordinary work of the colliery will not be required for the sinking operations, except under extraordinarily difficult conditions. This new type of engine, which is manufactured by the Messrs. Robey and Co., offers very great advantages for the temporary purposes of sinking. No strong foundations or buildings are required beyond a light shed to protect it from the weather; it is exceedingly compact, and can be brought upon the ground almost in a state to receive steam; it may be readily removed when its services are no longer required; it is very economical of fuel; its first cost is light; and it may be built of any power up to 200 horse. In all ordinary cases, this engine may be made to do both the winding and the pumping, when pumps are used. The following is a general description of this type of engine, the form and appearance of which is well known. The dimensions are those of the largest size engines, capable of working up to 200 horse-power effective.

The general arrangement is that adopted for the locomotive; but the frames are suppressed, and the engine is erected upon a massive cast-iron bed-plate, formed at one end into an ashpit, with damper doors, which carries the fire-box end of the boiler; the other end is carried by a saddle casting, fixed over the cylinder. The end of the bed-plate under the cylinder constitutes a feed-water tank, into which the cylinder cocks discharge all the condensed water, and into which also

a portion of the exhaust is directed to heat the feed-water to near the boiling point before it is forced into the boiler. The latter is bolted to the cylinders at the smoke-box end, and as the fire-box is carried on small rollers, it is free to expand on steam being got up, no strain being thrown upon either the plates or the joints. Upon the bed-plate, is fixed one plummer block and bearing for the winding drum. This drum stands by the side of the engine, the outer bearing being carried on a heavy balk of timber. The drum is 9 feet diameter, lagged with oak, and made up with cast-iron ends. On the end next the engine, is bolted a spur wheel 8 feet 4 inches diameter. On the end of the crank-shaft is keyed a pinion 2 feet 4 inches diameter, which gears with the spur wheel. Both these wheels are shrouded on one side. They are 9 inches wide on the working faces of the teeth, and 4 inches pitch. They work smoothly and quietly at a high velocity, the drum, when winding, running at the rate of twenty-four or twenty-five revolutions a minute, and the engine a little less than four times as fast. Two brakes are fitted to the engine; one to the fly-wheel, which is the one ordinarily used, and an extra one, of great power, round the drum itself. This last is provided to avert an accident, should the spur wheel or pinion give way. The whole of the parts of both the engine and the boiler being erected upon one bed-plate, heavy and expensive foundations are rendered unnecessary. The weight of the boiler and its contained water tends to keep the whole machinery firmly in position. All the levers for working the engine and the winding gear are brought together near the fire-box, so that one man may attend to both the driving and the stoking. The principal dimensions of such an engine are as follows: Cylinders, each 16 inches diameter by 24-inch stroke; crank-shaft, bent out of one piece of Lowmoor iron, $6\frac{3}{4}$ inches diameter; drum shaft, best scrap, 10 inches diameter; drum, 9 feet diameter by 6 feet wide, cast-iron ends, lagged with best English oak; boiler, 10 feet 10 inches long, by 4 feet 9 inches diameter; fire-box, 5 feet 9 inches long, and 4 feet 9 inches wide; tubes, seventy-four in number, and 3 inches in diameter; working pressure, 100 lb. to the square inch.

The engine to which the foregoing dimensions relate is a very powerful one. In most cases, one of much less power will be sufficient. In the case assumed for the purpose of illustration, it is supposed that an engine of this class, capable of working up to 50 H.P. effective, is erected to continue the sinking below the first length of walling. To enable the engine to draw from the two shafts which are being sunk simultaneously, it should be erected between them. The details of such an arrangement are too obvious to need description.

Drainage.—The sinking having reached a point at which moderate quantities of water will be met with, means must be provided for draining the bottom of the excavation. The streams of water which enter the excavation through fissures in the rock are called "feeders." Surface feeders are such as are in direct communication with the surface; these, of course, are influenced by the weather. Partial feeders are those which are in communication with a cavity containing water; they gradually decrease after being opened, and in time become entirely exhausted. Permanent feeders are such as derive their water from inexhaustible sources, and, therefore, continue without diminution. Feeders are shut back by means of tubbing, to be hereafter described. The smaller quantities of water that escape from the strata into the excavation must be raised to surface either in tubs by means of the drawing engine, or by means of pumps. When the latter are used, they may be worked by the same engine that does the drawing. The question of drainage by means of pumps will be treated in a subsequent chapter; in this place, therefore, we have only

to consider the method of drawing the water in tubs. This method is sufficient whenever the quantity of water met with is not great. Even when the quantity is considerable, it may be advantageously removed by this means in many cases where pumps are usually resorted to. Winding is a far cheaper mode of raising water than pumping.

The tub commonly used for drawing water is of iron, and is similar in shape to the kibble, that is, it is barrel-shaped. The capacity of these tubs varies, but frequently it is about 100 gallons, when it is intended to be drawn by the engine. The tub is suspended by a bow turning on two pins placed a little below the centre of gravity, on the outside of the tub, as shown in Fig. 399. The object of this arrangement is to facilitate the discharge of the contents on arriving at surface. Besides the larger bow which turns upon the pins forming the points of suspension, there is a smaller one fixed to the tub, and passing freely beneath the former. On one side of the tub is a spring catch, which, by laying hold of the larger bow, prevents the tub from tilting in the shaft. When the tub is raised full of water to the top of the shaft, the waiter-on seizes the smaller bow, and, releasing the spring catch, pulls the tub over, discharging the water into a shoot, by which it is conveyed away. The position of the centre of gravity above the axis upon which the tub turns renders the operation of tipping an easy one. When the contained water has been discharged, the man pushes the tub back into the vertical position, where it is seized by the spring catch; in this state it is ready to be again lowered into the shaft. An objection to this kind of tub is that it does not fill well, the water having to flow into it over the top.

The objection to the tub described above may be removed by constructing it with a valve at the bottom, through which the water can enter. This arrangement has been adopted in a very neat and effective manner by Mr. C. Bromley, the engineer in charge of the sinking already referred to. Fig. 395 represents a vertical section of the tub or bucket as constructed by that gentleman. The bottom of this tub, which is about 5 feet in height and 3 feet in diameter, is provided with a circular aperture 20 inches in diameter; this aperture is covered by an iron disc or valve B, mounted on a central spindle A, which moves between guides D and E. The under side of the disc is faced with a ring of vulcanized indiarubber, to enable it to close water-tight. When this tub is lowered into the water, the pressure of the latter forces up the valve B, and the tub fills. When the tub is full, the valve drops upon its seating, and retains the water. The mode of emptying this tub, and conveying away the water, is very simple. In the end wall of the rectangle shown in Fig. 393 is fixed a drain pipe, 2 feet in diameter, leading to a channel provided to convey away the water. A wooden shoot, C, leads from the flooring to this drain pipe; and on the platform B rests a trough about 8 feet wide and 2 feet deep, open at the end next the shoot. When the tub is raised to a height slightly above the mouth of the shaft, as in the case of the loaded kibble, the waiters-on push the platform forward over the mouth of the shaft until the closed end of the trough is under the tub. The latter is then lowered gently on to the trough, when the projection F of the spindle coming in contact with the planking, the valve B is forced up till the tub comes to rest upon the stops X X. The water issues through the valve aperture, and flows down the trough into the shoot, and is conveyed away through the drain pipe in the end wall. Thus it will be seen that the apparatus is self-acting, and it has been found in practice to fulfil the purpose intended in a very satisfactory manner. A tub of this construction, and of the dimensions shown, weighs about 900 lb., and contains about 220 gallons of water.

Ventilation.—When the excavation has attained the depth of from 15 to 20 yards, the ventilation

will become defective, and means must be provided for directing a sufficient current of air down to the workings. These means may be of several kinds, according to the requirements of the case. The air-box will for some time give an adequate ventilation, and may be advantageously employed until a considerable depth is attained. The air-box is a wooden pipe, generally about 12 inches square, outside dimensions, made of 1 inch, or $\frac{3}{4}$-inch deal boards, the joints of which are made to fit truly, and tarred, or if necessary, pitched, to render them fairly air-tight. This pipe is fixed against the side of the shaft, and carried down to near the bottom. In order not to encumber the mouth of the shaft, the pipe, on reaching within a few feet of the latter, is passed through the walling, and carried in an inclined direction to surface, at a convenient spot a few yards distant. Over the aperture of the pipe at this spot a chimney is roughly built of bricks, in which a fire is kept burning, or into which a steam jet is turned. Instead of erecting this special chimney, the pipe may be put into communication with one already existing, the engine stack, for example. The rarefaction of the air in the chimney, occasioned by the fire or the steam, causes it to ascend, by a well known law; and as this air can be replaced only by that which is in the pipe, a constant current is maintained down the shaft and up the pipe. As the lower end of the pipe cannot be brought close down to the workings by reason of the danger to which it would be exposed from the shots, a flexible canvas tube, called a "bag," is attached, which is dropped lower as the sinking proceeds. When the workings have receded too far from the wooden pipe, the latter is lengthened. It will be necessary to keep a considerable current of air passing through this pipe; for besides the large quantities of powder smoke that have to be carried off, carbonic acid gas, or choke damp, may exude from the joints and fissures in the rocks; and in passing through thin seams of coal, or on approaching the thicker seams, blowers of inflammable gas may be met with.

When the depth of the shaft has become great, or earlier if the rock is foul with gas, the foregoing method of ventilation will be found insufficient. Recourse must then be had to the plan of "bratticing" the shaft, that is, of dividing it by a wooden partition, called a brattice. The purpose of the bratticing is to divide the shaft into two unequal air-tight compartments, the larger of which, devoted to the drawing of the stuff, may serve as a downcast, and the smaller of which, reserved for the pumps, may serve as an upcast. The arrangement is obviously of the same nature as that of the air-box, previously described; but the important difference is that the brattice gives a very much larger air-way than the box. When the brattice has been put in, the ventilation will proceed naturally, the current descending on one side, and ascending on the other side of the brattice. Under such conditions, however, the air current will not always descend through the same compartment, the direction being dependent upon certain external causes, such as the direction of the wind, and the existence of objects affording shelter. When this natural ventilation has become insufficient, the top of the smaller compartment is planked over, and the space below placed in communication with a chimney, through an inclined passage, as in the case of the air-box, as shown in Fig. 392; or, in some cases, with a small fan erected to exhaust the air from the shaft. By such means as these a very efficient ventilation may be maintained.

In determining the position of the bratticing, the permanent divisions of the shaft must be considered, and the bratticing placed in accordance with them, for this bratticing will form one of the permanent divisions, even if it be at first constructed in a temporary manner with a view to its being replaced by a more substantial structure when the shaft is completed. There are two methods adopted of constructing the bratticing, one of which is known as the "bunton" system, and the other

as the "plank" system. In the former, deal battens, 7 inches × 3 inches in section, are fixed against the sides of the shaft, one on opposite sides, from the top to near the bottom. As these pieces, which are called side, or stringing planks, are to form the support for the bratticing, they must be firmly fixed to the shaft. The method of fixing them is to drill holes in the walling to a depth of not less than 12 inches, and to plug these holes with wood to give a sufficient hold for the spikes to be used. The stringing planks are then fixed to the sides of the shaft by means of spikes driven into these holes. Where the shaft is lined with metal tubbing, the planks are spiked to the joints of the tubbing. At intervals of 3 feet, from centre to centre, the stringing planks are provided with notches to receive the ends of other battens, called "buntons," placed horizontally from stringing plank to stringing plank across the shaft. These buntons are fixed to the side supports with nails, and are intended to support the cleading or sheathing which is to constitute the brattice. This cleading consists of fir boards from 1 to 2 inches thick, according to the character of the bratticing, whether temporary or permanent, nailed vertically upon the buntons. These boards are planed true on the edges, so as to form air-tight joints, and in nailing them in position care is needed to keep the joints close. When the brattice is to be permanent the joints are "slivered;" that is, a thin strip of wood, called a "sliver," is inserted into a groove ploughed in the edges of two corresponding boards.

The "plank" brattice is of more simple construction than the foregoing, and is to be preferred as a permanent structure. In this system of bratticing, two side planks are used upon each side of the shaft, placed at an interval of 3 inches apart, and the buntons are dispensed with. The brattice boards in this case are 3 inches thick, and are placed horizontally, edge upon edge, by being slid down the grooves formed on opposite sides of the shaft by the side planks. The joints in this kind of brattice are kept firm and air-tight by planing the edges of the boards true and dowelling them with iron dowels, or preferably by means of oak slivering, as previously described. Sometimes, when iron tubbing is used, the latter is cast with grooves to receive the boards, in order to dispense with the stringing planks. Whatever the nature of the bratticing, it must not be carried, during the sinking, nearer to the bottom than 20 feet, because of the injury which might be caused to it by the firing of shots. Another precaution which it is very important to observe, to secure the brattice from injury during the progress of the sinking by the ascending kibbles coming into contact with the under side, consists in placing beneath it, at intervals apart so as not to materially impede the ventilation, sliding deals, similar to those placed beneath the covering of the shaft at surface, already described.

Sinking in Compact Rock.—We have now to consider the operations of sinking below the first length of walling, that is, the continuation of the sinking in the rock. In the case assumed, it is supposed that the rock is of a moderately compact and strong character, yielding but little water, and capable of standing without support.

On resuming the sinking beneath the walling, the excavation is carried down in a line with the inside of the wedging curb for a distance of about 3 feet, and from that point gradually enlarged to the full diameter. This enlargement should be proportioned so as to make the sides of the excavation, from the point at which the enlargement begins to that at which it terminates, form an angle of about 60° with the horizontal. By this means a kind of bracket is left for the support of the walling. Beneath this bracket the excavation is continued down of the full diameter. When a depth has been reached at which walling becomes necessary, a wedging curb is laid in the manner

already described, and the walling is built up upon it, till the lower portion of the rock bracket is arrived at. This bracket is then cut away in small portions at a time, and the walling carried up to the under side of the wedging curb. During this part of the work, it will be necessary to support the wedging curb of the upper length of walling, at the points from which the rock has been removed, by vertical props set upon the lower walling. The greatest care should be exercised to make the latter join well and closely up to the wedging curb, which will thus divide the two lengths of walling. In some instances, the wedging curb has been removed in small portions at a time with the chisel, and the brickwork made to join; but this is not often attempted.

This portion of the sinking being in compact rock, the excavation will be carried on by means of blasting. The details of these operations have been fully described in a former section. The mode of procedure in shaft sinking is precisely the same as that followed in a heading, which procedure is illustrated on Plate XXXIII. The first operation, as therein shown, consists in unkeying the face, which is effected by angling the shot holes, in the manner described when treating of the heading. As in the latter case, the unkeying is from the centre of the face, that is, the bottom of the excavation. When the strata are highly inclined, however, it is better to unkey from one side of the excavation. The water which flows into the workings must be collected into one place, both for convenience in raising it, and for the purpose of keeping the surface of the rock clear for the sinkers. The depression caused by the removal of the key serves for the purpose of collecting the water, and is called on that account the " sump," or well. Into this sump the tub dips, or, if pumps are used, the suction hose is dropped. When the rock beds are highly inclined, the water gravitates towards the dip side of the excavation, and it therefore becomes necessary to place the sump in that situation. The unkeying of the rock from this direction is, moreover, favourable to the action of the shots under the conditions of highly inclined beds. In putting in the shot holes, care must be taken not to terminate them in, or nearly in, a bedding plane, because when so situate the force of the charge expends itself along this plane.

When the shot holes are bored by machine drills, the most favourable position for the holes cannot always be adopted. Mention has already been made of this matter, and it will be again considered in the next chapter. In sinking with the machine drill, the tripod support is of very little use. Under such conditions, the stretcher bar should always be adopted. The machine is suspended from this bar, and slid along from one end of the bar to the other, by means of the clamp. Hence arises a necessity for placing the holes in straight rows. When all the holes that may be reached from the bar have been bored, the latter is shifted, and a new series commenced. It will be evident, on reflection, that the labour of changing the position of the stretcher bar will occupy much time, and that, consequently, any attempt to obtain the advantage due to the most favourable position and direction of the shot holes must be useless, since what is gained on the one hand is lost on the other. Hence it becomes necessary to determine the position of the holes rather in accordance with the exigencies of machine labour, than with those of the greatest useful effect. It is, however, of the greatest importance that these conflicting conditions should be fulfilled in the highest degree possible; in other words, that the greatest possible amount of useful effect should be sought consistently with a due satisfaction of the conditions imposed by the employment of the machines. To obtain this result, it is necessary to place the machine so that the required number of holes may be bored with the fewest possible changes of position of the stretcher bar, and then to place and to direct the holes in a manner that will give the best effect to the charges. To unkey the face

from the centre, sometimes several holes are bored near together, and the charges fired to crush the rock between them, after the manner described in a former section. This is probably the very worst method of unkeying a face of rock. A more common method is to angle a single hole in the centre, and to fire it with a heavy charge to take out the key and form the sump. Unkeying from one side will, however, be found generally the most favourable to machine labour. The usual method of setting the stretcher bar in a shaft, and of applying the drill under such conditions, will be understood from the drawing, Fig. 401.

Another method of using the stretcher bar, commonly adopted in France and in Belgium, and recently introduced into England, is shown in Figs. 402 and 403. A central support, or leg A, is placed in the middle of the shaft, and four wooden arms, radiating at right angles to one another from the central leg or support, extend to the sides of the excavation. These arms are fixed firmly in position by means of a lengthening screw, in the same manner as the stretcher bar, and the central support is tightened in position by the same means. A block of wood is usually placed between the points of the arms and the rock, to give the former a better hold. The arms *a*, *b*, *c*, *d* are shown thus fixed in position in Figs. 402 and 403. Upon the top of the central leg and the inner ends of the arms is an iron plate, provided with holes at *e*, *f*, *g*, *h*, for the purpose of attaching one end of the stretcher bar. When the bottom of the excavation is ready for boring, the supports are firmly fixed in the manner described, and the stretcher bar is set in position by attaching one end to the centre plate through the hole *h*, and screwing the other up against the side of the shaft, as at *x*. If two machines are to be used, the second is set in the same manner on the opposite side, by fixing it into the hole *f* of the centre plate. The machines being set at the required angle, the necessary number of holes between the centre and the sides of the excavation are bored by sliding the machine along the bar, by means of the ordinary clamp arrangement. When these holes have been bored, the end *x* of the bar is loosened, and removed to the point *y*, where it is fixed as before, the bar being turned upon *h* as an axis. When all the holes required in the quadrants formed by the arms *a d* and *b c* have been put down, the stretcher bars are detached from the centre plate at *h* and *f*, and refixed to the plate at *e* and *g*. The holes required in the other two quadrants or divisions of the circular face are then bored in the same manner, and the face is ready for the blasters. The holes bored by this method are necessarily in concentric circles, but the angling may be varied as desired. When the blast is ready for firing, the arms of the support are loosened, and the whole is drawn a sufficient distance up the shaft to remove it beyond the reach of harm from projected pieces of rock. In order not to encumber the shaft when in this position, and to facilitate its withdrawal, the arms of the support are frequently made to hinge in the centre, so as to allow them to drop down when the support is lifted by the central boss. If only one, or if three machines are to be used, three arms, disposed as in Fig. 404, should be preferred to four.

A method of using the machine drill has recently been introduced by Mr. W. B. Brain, in which it is sought to fulfil the two sets of conditions, namely, those due to the exigencies of machine labour, and those involved in the attainment of the greatest useful effect from a given charge, in the fullest possible degree. This method constitutes, indeed, a new system, both of applying the drill and of placing the charges; and the success which has everywhere attended its adoption shows that the end proposed has, in some degree at least, been attained. In Brain's system, which is known as the "radial system," the holes of each series, 1, 2, 3, 4, 5, Fig. 406, or as many of them as possible, are made to radiate from some fixed point A, Fig. 405, which point represents the position

of the clamp on the stretcher bar. When all the holes in one series have been bored, the clamp is shifted a certain distance along the bar, and the next series is bored in like manner. The distance apart of the holes in a series, and also of the series themselves, that is, the distance between the series 1, 2, 3, &c., and 1, 2, 3; and also between the series 1, 1, 1, &c., and 2, 2, 2, &c., is determined beforehand, in accordance with the toughness of the rock and the strength of the explosive, and afterwards strictly adhered to, irrespective of joints, fissures due to former shots, irregularities of the face, or any other circumstance that may exist peculiar to the case. The angles of the holes in a series 1, 2, 3, &c., are also preserved through all of those series, so that all the holes in a series 1, 1, 1, &c., are in the same plane.

It will be observed that in this system the unkeying of the rock takes place from the side of the face by sharply angling the holes in that position, and that as many of the holes as possible are bored from one position of the stretcher bar. In general, unless the diameter of the excavation is very great, one change of position, from A to A′, will be sufficient. Thus it is evident that these changes have been reduced to the lowest limit in this system, and that, consequently, the loss of time due to the labour of changing has been brought to a minimum value. On the other hand, a certain loss of time is incurred in setting the machine to the required angle at each successive boring. It must be remarked, that this system was designed with a view to simultaneous firing, and the use of a strong explosive; and it is only by the fulfilment of these conditions that all the advantages of the system can be obtained. We shall have occasion to consider and to illustrate this method of machine boring more fully in the next chapter.

The blasting, especially if the shot holes have been bored by machine drills, leaves the sides of the excavation in a very rough state. These will, therefore, require to be subsequently dressed down by hand with the pick and the wedge.

Tubbing.—The sinking and walling of the shaft will be continued through the rock in the manner described until, we will suppose, for the purpose of fully illustrating our assumed case, water-bearing beds are met with. Down to this point, all the infiltering water has been raised to surface, without much difficulty, in tubs, or by means of small pumps. But when heavy feeders are met with, it becomes important to stop them back. The means by which this is accomplished consist of a water-tight wooden, or cast-iron lining, called tubbing, which is fixed in the shaft throughout that portion which passes through the water-bearing beds. Brick walling has been applied as tubbing, but its nature is not suitable to this purpose, and it is now very rarely used. Wooden tubbing was formerly employed in England, but its use has been almost entirely abandoned in favour of cast iron. It is, however, still very commonly adopted on the continent of Europe, and in other parts of the world where timber is plentiful. It is therefore desirable to describe this kind of tubbing, and the method of fixing it in the shaft, before considering that more durable kind which is composed of iron, and which is now generally adopted in England, particularly as many of the operations of fixing the tubbing are identical for both kinds. The operations of sinking through water-bearing beds, and of tubbing the shaft throughout that portion of its length, are beset with difficulties, and their successful accomplishment demands the application of knowledge, skill, and, above all, energy.

The sinking beneath the last wedging curb supporting the walling is carried down a few feet in a line with the inner face of the curb, to form a support for the latter, as already described, and then gradually laid off to the diameter, in the case assumed, of 15 feet 6 inches, for metal tubbing; and to about the same diameter for wooden tubbing. From this point, the sinking should be carried

down through the permeable bed to the impervious bed beneath with all possible speed. Promptitude is here one of the conditions of success; for when a water-bearing bed is pierced, the water, which is often under great pressure, issues in great abundance into the excavation, and this abundance increases as the water clears itself a passage through the interstices of the rock. When the impervious bed has been reached, the sinking will be brought into its net size of 13 feet, and continued down till a good foundation is found for the wedging curb. At this point, the sinking, after being carried down 4 or 5 feet farther to form a sump for the water, will be shorn back to receive the wedging curb. The latter is of oak, and similar to that used for the walling, but of somewhat larger sectional dimensions; the joints require to be fitted with greater care, thin slit deals being placed between them, and the rock bed must be prepared and levelled with perfect accuracy for its reception. As the wedging has a tendency to lift the outer edge of the curb, the bed should have a slight inclination outwards, so that the upper surface of the curb may be perfectly level when the wedging is completed.

When laid in position, the wedging curb should be everywhere about $2\frac{1}{2}$ inches from the sides of the excavation, so as to leave an annular space of that width between it and the rock. Care should be taken to see that the rock be perfectly sound in this part; if joints or small fissures exist here and there, they must be well stopped with clay, or, in some cases, caulked with oakum. A fir sheathing $1\frac{1}{2}$ inch thick is placed next the curb in the annular space between it and the rock; the breadth of this sheathing is a little greater than the depth of the wedging curb, so that when in position it stands a little above the latter. When the shaft is circular, as in the case assumed, saw-cuts at every three inches across the sheathing, that is, at right angles to its length, will be required, to enable it to adapt itself readily to the shape of the curb. The fir sheathing is forced into close contact with the curb by means of wedges driven in at intervals, and the space between it and the rock is filled in with moss or with oakum, usually the former. The moss must be forced in until it is incapable of further compression, when the wedges will have to be withdrawn, and their places also filled with moss in a like manner. At this stage the curbing will appear as in Fig. 407. The prop, which is set upon the joint of the curb, and made to abut against the rock above, as shown in the figure, is needed to prevent the curb from rising during the operations of wedging.

The curb is now ready for wedging, which is performed in the following manner: Between the curb and the sheathing, carefully prepared wedges are driven in, to force the sheathing and the moss behind it firmly back against the rock, so that the curbing, when finished, shall make a perfectly water-tight joint. The wedges are of soft wood: poplar, where this is readily procurable, as in France; and fir in other localities. It is essential that these wedges be uniform in dimensions. In form, those first applied will be broad and flat, and called on that account "flat" wedges; afterwards narrower wedges of a pointed form, sometimes called "spiles," will be required. These flat wedges are inserted close together all round the curb, the edge being slightly driven in to keep them in position. When all the wedges are thus inserted, they are driven in as equally and as nearly simultaneously as possible. This wedging drives the sheathing back from the curb, and compresses the moss tightly against the rock. The next operation is to double the wedges; this is performed in the following manner: An iron wedge, of greater thickness than the wooden ones, is driven in for the purpose of loosening the wooden wedge next to it, by taking the pressure from the sheathing. When this wedge is thus freed, it is taken out, and another one substituted for it, head downwards. A second wedge of the same dimensions is then inserted, point downwards, between the upturned

point of the first and the sheathing. This operation is repeated all round, until all the wedges have been doubled; after which the driving is continued as long as the wedges will move. At this stage the curbing will appear in section, as in Fig. 408, which shows four concentric lines, consisting of the curb, the wedges, the sheathing, and the moss.

When the wedging has been completed up to this point, a quadrangular iron wedge, steeled at the tip, is taken and driven in successively between the flat wooden wedges, for the purpose of inserting the point of a fir spile. These spiles are driven into the interstices between every two wedges, until they refuse to penetrate farther. When these are all driven down, the whole of the curbing is tightly wedged in all directions, and the moss has become so compressed as to be hardly visible; the heads of all the wedges and spiles are then adzed down. Next, the heads of all the flat wedges are cleaved with a steel-tipped iron wedge, and oak spiles, previously well dried in an oven, are inserted in the cleft, and driven in as far as they will go. This operation of cleaving the wedges is continued as long as a spile can be made to enter. When no more can be got in, the whole is adzed down to form a level surface. The curbing is then complete, and appears as shown in Fig. 409, which represents two curbs superposed for greater security. Sometimes three such curbs are laid; but commonly there are but two. It is important that the wedges should be put in dry, because when in that state their dimensions are at a minimum, and by swelling, on exposure to moisture, they still further tighten the joint. It is for this purpose that the last wedges inserted are dried in an oven. Fig. 410 shows a plan of the wedging curb when completed; the four concentric circles representing the curb itself, the wedges, the fir sheathing, and the moss. Precisely the same method of fixing the wedging curb is adopted when the shaft is polygonal, as it frequently is on the Continent. Fig. 411 is a plan of the curb as constructed for such a form. The mode of putting in the fir sheathing under these conditions will be understood from the drawing.

When the wedging curbs have been laid, the tubbing is built up upon them. This tubbing consists of wooden curbs, constructed similarly to the wedging curbs, and built up one upon another throughout the whole length of the shaft to be tubbed. These curbs are generally about 8 inches broad on the bed, and 10 inches in depth. It is by no means essential that they should be all of the same depth, and in practice they are never equal in that respect. Their thickness will be determined by the pressure which they will be required to support; which thickness will, therefore, diminish as the tubbing rises towards the surface. The beds of the curbs should be truly dressed, in order that a water-tight joint may be made subsequently by merely caulking it. When the height of the tubbing is considerable, a broader curb, called a bearing curb, is put in at intervals of 8 or 10 yards, and firmly wedged against the rock. These bearing curbs take the weight of the tubbing off the wedging curbs at the bottom. Tubbed in this way, the shaft appears as in Fig. 412. The space behind the tubbing is filled up with strong concrete. This concrete backing is an important adjunct to the tubbing, as it penetrates into every hollow and fissure, and on hardening it forms a strong protective casing around the tubbing. The existence of such a casing greatly facilitates the operation of replacing a faulty curb by a sound one after the completion of the shaft.

It now remains to consider the method of tubbing with cast iron, as generally practised in England, and commonly in other countries where wood is not very abundant.

In the case of iron tubbing, the wedging curbs are themselves of cast iron, and hollow. Sometimes they are open on the outside and sometimes on the inside, and are divided at intervals by partitions to give strength to the curb. The hollows between these partitions are filled with oak. In

some cases, the curb is not open on either side. Generally, these curbs, of which examples will be given hereafter, are about 13 inches broad, and 6 or 7 inches in depth, the thickness of the metal being about $1\frac{1}{4}$ inch. Such cast-iron curbs are put together in segments, and laid upon a bed of $\frac{1}{2}$-inch fir sheathing. Oak sheathing is inserted between the joints, which are made firm by wedging. This sheathing should be cut and placed in such a way that the grain may run towards the centre of the shaft, and it should be made to taper from the outer towards the inner face of the curb, say from a thickness of 1 inch on the outside to $\frac{5}{8}$ inch or $\frac{1}{2}$ inch on the inside. The method of fixing the iron wedging curb is in all respects the same as that adopted for the wooden curb, which has been fully described. Sometimes a wooden wedging curb is first laid, and an iron one then laid upon it; oftener, two iron curbs are laid one upon the other.

The plates of the tubbing, like the wedging curbs, are cast in segments, the dimensions of which require from eight to twelve to form a circle of tubbing. These segments vary from 12 inches to 36 inches in height, according to the pressure they are designed to withstand, and from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inch in thickness. They are smooth on the inside so as to form a regular surface in the shaft, but on the outside, next the rock, they are strengthened by ribs and flanges, supported by brackets, as shown in Fig. 413. These flanges form the edges of the segment, and they should be cast perfectly true, so as to form a regular joint when two segments are brought into contact. The top and one of the side edges are provided on the outside with a projection or flange, the use of which is to retain the joint sheathing and two adjoining segments in their positions. These flanges may be called "retaining" flanges. Every segment has a hole in the middle, to allow the water to escape during the operations of setting. This hole is made use of in lowering the segments and in placing them in position. It is of essential importance that these castings be perfectly sound in every part. The method of setting the segments is as follows: A sheathing of pitch pine, $\frac{3}{8}$ inch or $\frac{1}{2}$ inch thick, is laid upon the upper surface of the wedging curb, to form the joint between it and the first course of tubbing; the breadth of this sheathing will be from 4 to 5 inches. A course of tubbing is then set upon this bed all round the shaft, and fir sheathing, from $\frac{1}{4}$ inch to $\frac{3}{8}$ inch thick, is placed between the joints, in the same manner as was required for the wedging curb. In order to close up the joints and to steady the tubbing in position, two strips of wood, an inch thick and from 4 inches to 6 inches broad, may be placed behind the vertical joints, between the tubbing and the rock; and a third strip, thinned off towards the end to form a wedge, driven down between them. The space between the tubbing and the rock is next filled in with loose rock from the excavation, or, preferably, with good concrete. When the latter is used, it will be well to remove the wedging strips behind the vertical joints as the concrete is put in. Upon the top of this first course of tubbing, pine sheathing is laid to form the horizontal joints between the courses, and a second course is set up upon this, and fixed in position in the same manner as the first, always taking care that the joints, both horizontal and vertical, be very accurately made. The latter must be broken, that is, the vertical joints of the second course must be over the middle of the segments forming the first course. These operations are repeated until the stone bracket supporting the wedging curb beneath the walling is reached. This rock is then cut away sufficiently to afford room for the tubbing, leaving a portion of the thickness to support the walling, and the tubbing completed up to the wedging curb. The joints have now to be tightened by wedging, which is effected in the following manner: Beginning at the bottom, incisions are made with a broad chisel in the sheathing, and broad flat wedges are driven into the clefts thus made. These wedges are about 4 inches broad and $\frac{3}{8}$ inch thick at the head. When the joints have

been filled with these, a square-pointed steel tool is used to make fresh incisions, and spiles or square wedges of the same thickness are driven in wherever it is possible to make one enter. The joints between the top course of tubbing and the wedging curb beneath the walling must also be tightly wedged. The plugging of the holes in the centre of each segment is also commenced from below. When the head of water is great, there is some difficulty in inserting the plug on account of the force with which the water issues. After the plug has been driven in as tightly as possible, the head is cleaved with a chisel, and an oak wedge driven into the cleft to increase the hold of the plug. Care must be exercised in plugging not to proceed too rapidly, because it is necessary that any air or gas that may be imprisoned behind the tubbing should be allowed to escape.

As the corroding action of water is very destructive to cast-iron tubbing, means must be adopted for protecting it. A thick coating of tar or of paint will be found sufficient in some situations. When the shaft is an upcast, and the mine is ventilated by a furnace, or when there are engine fires underground, the destruction of the tubbing may proceed rapidly. In such a case, a lining of brick may be inserted; but such a lining renders it difficult to repair the tubbing or to stop a leaky joint. Of course, when a lining of this nature is contemplated, the diameter of the excavation must be determined accordingly. Sometimes a lining of wood is put in to protect the tubbing. Such a lining should consist of deals 2 inches thick, having their edges properly beveled to form close joints.

Cast-iron tubbing is more difficult to construct and to repair than wood tubbing; but it is far more durable under ordinary conditions, and it is capable of resisting a much greater pressure of water. The wood tubbing may be used with safety down to a depth of 100 yards; and in localities where wood is abundant, its adoption will occasion a notable economy. But for greater depths, iron tubbing is alone suitable. The thickness of cast-iron tubbing will be determined, as far as the exigencies of practice will allow, by the pressure which it will be required to sustain. The following formula gives the maximum thickness for segments not exceeding 2 feet in depth, H being the head of water, and D the diameter of the shaft, in feet, and T the thickness of the plate, in inches:

$$T = 0 \cdot 35 + 0 \cdot 00025 \, H \, D.$$

Thus, if $H = 200$ and $D = 14$, we shall have $T = 0 \cdot 35 + 0 \cdot 00025 \times 200 \times 14 = 1 \cdot 05$ inches, as the requisite thickness. In practice, the thickness is generally varied at every 25 feet.

The following examples of tubbing, which have been executed in England and in different localities on the Continent, may be studied with advantage. They constitute the principal types now in use, and for that reason they have been selected as illustrations. It is obvious that in constructions of this character very little modification can be made beyond varying the arrangement of the strengthening ribs and flanges, and the number of segments in a course.

Some of the earliest examples of a complete system of cast-iron tubbing may be found in the north-eastern coal districts of England. In one of these, to which the following particulars relate, the shaft is 14 feet in diameter; it is walled down to a depth of about 25 yards, and from this point to a depth of about 172 yards it is tubbed with cast-iron tubbing. This tubbing is composed of eight segments to the circle, 1 foot in height, and $1\frac{1}{8}$ inch thick, in the lower portion; and 2 feet in height, and $\frac{3}{4}$ inch thick in the upper portion. Each segment is strengthened by a horizontal rib in the middle, and two vertical ribs; and the hole in the middle is surrounded by an increased thickness of metal, forming a boss. The overlap or retaining flanges are $\frac{1}{2}$ inch in depth, and $1\frac{1}{2}$ inch in breadth. The wedging curb is open on the outside, each segment having three vertical diaphragms or

partitions, which divide the interior into four portions. These are filled with oak, which projects slightly to form a face to wedge against. The depth of the curb is 6 inches, its breadth is 12 inches, and the thickness of the metal is $1\frac{1}{2}$ inch. This is the type of tubbing described in the foregoing paragraphs, and generally adopted both in England and on the Continent.

Another very good example of cast-iron tubbing was erected in 1856, in the Basin of the Ruhr, Westphalia, by an English engineer. The tubbing in this case is of the same type as that described above. The diameter of the shaft is 12 feet, and the length tubbed is about 120 yards, through strata consisting of sands and marls. As in the preceding example, a course is composed of eight segments; the height of a segment is 2 feet, and the thickness was begun at $\frac{9}{16}$ inch, and increased $\frac{1}{8}$ at every 20 metres—about 22 yards—of depth, reckoning from the surface downwards. Thus the thicknesses are as follows:

Depth, 20 metres.	Thickness, $\frac{3}{4}$ inch.	Depth, 80 metres.	Thickness, $1\frac{1}{8}$ inch.
„ 40 „	„ $\frac{7}{8}$ „	„ 100 „	„ $1\frac{1}{4}$ „
„ 60 „	„ 1 „	„ 120 „	„ $1\frac{3}{8}$ „

The wedging curb is 6 inches in depth, 14 inches in breadth, and 1 inch in thickness of metal. American pine was used for the joint sheathing, and the same wood was used for the wedges in the joints. The greatest quantity of water to be dealt with was about 265 gallons a minute. This was encountered at a depth of 83 yards.

A third noteworthy example may be taken from the coal-fields of the north of France, where a length of tubbing was put into a shaft by M. Demilly, chief engineer to the Société Houillère de Fiennes, in the year 1858. The portion tubbed was from 171 to 182 metres from surface, giving a length of 11 metres. The first 50 metres was tubbed with the solid wood tubbing described in a former paragraph. From this depth to that of 100 metres, no water was met with; but below 100 metres, 5 metres of tubbing had to be put in, and another length of 8 metres, below the depth of 120 metres. The sinking was through jurassic strata, and the upper carboniferous limestone, and the water was met with at the junction of the limestone and the coal measures. The quantity of water did not exceed 70 gallons a minute. The excavation was carried 7 metres into the coal measures to obtain a suitable bed for the tubbing, the height of which was to be 11 metres, 4 metres being in the limestone. Three wedging curbs were laid below and above the tubbing. These curbs are double, as shown in Fig. 414, the inner one being 12 inches, and the outer one 8 inches broad. Both are 8 inches in depth, and are open on the side towards the shaft; each segment is divided internally by three vertical partitions into four compartments. These compartments are filled with oak. The space of $1\frac{1}{8}$ inch between the curbs is firmly wedged. The tubbing, which has an internal diameter of 13 feet 4 inches, is composed of twelve segments, constructed as shown in Figs. 415 to 418. The overlap or retaining flanges are represented at *a b* and *c d*; the height of the segment is 16 inches; it is strengthened by two horizontal and one vertical rib, and provided in the middle with a hole $1\frac{1}{2}$ inch in diameter. The joint sheathing used was of fir, $\frac{3}{8}$ inch in thickness, and the wedges were also of fir. The horizontal joints are made to taper towards the centre of the shaft, the sheathing being $\frac{3}{8}$ inch thick on the inside, and $\frac{3}{4}$ inch on the side next the rock. M. Demilly thinks that two or three shallow grooves in the upper edge of the segment would give a better hold upon the wood. He is also of opinion that it would have been better to have used segments of 2 feet in height, and of 16 rather than 12 to the circle.

A final example of recent construction may be taken from the coal-fields of Schœneck, at Styring

(Moselle). The shaft in this case is 13 feet 4 inches in diameter, and it is tubbed with wood from a depth of 20 metres to that of 105 metres; and from this depth to that of 130 metres, which is within 2 metres of the bottom, it is tubbed with cast iron. The wedging curbs in this case, shown in Figs. 419 to 421, are 14 inches in breadth, 8 inches in depth, and of the same thickness as the bottom courses of tubbing. Each segment is open on the side next the rock, and divided internally into four compartments. These compartments are filled with oak. The upper surface of the curb is not level, but indented, as shown in the drawing, to receive the fir sheathing upon which the tubbing is to be set. The bed of the wedging curb was cut with a slope of $\frac{3}{8}$ inch towards the sides of the excavation. After the wedging had been performed, the upper face of the curb was found to be perfectly horizontal. The sheathing used for the joints of the curb was of oak, and planed down to a thickness at the four angles of 22, 25, 28, and 30 millimetres = 0·86, 0·98, 1·10, and 1·18 inch. The sheathing placed behind the curb was of poplar, in pieces of 5 feet 10 inches long, 10 inches broad, and $1\frac{1}{8}$ inch thick. Saw-cuts, $\frac{1}{2}$ inch in depth and $1\frac{1}{2}$ inch apart, were made perpendicularly to the length of the piece, to enable it to assume readily the circular form. The segments of tubbing are shown in Figs. 422 to 424; ten of these constitute a complete course. Each segment is 20 inches in height, and it is strengthened by one horizontal and three vertical ribs. The thickness of the plates was varied at every 10 metres. Thus, the thickness at a depth of 100 metres is 30 millimetres = 1·18 inch; at 110 it is increased to 32 millimetres = 1·26 inch; at 120 it is 35 millimetres = 1·37 inch; and at 130 it is 38 millimetres = 1·50 inch. The central hole in each segment is $1\frac{1}{2}$ inch in diameter. The vertical joints of the tubbing were made with oak sheathing 0·44 inch in breadth, 0·70 inch thick on the front, and 0·39 inch thick on the back face. The horizontal joints were made with poplar sheathing of the same dimensions. The wedging was done with oak wedges in the vertical joints, and with poplar and oak wedges in the horizontal joints. The flanges forming the edges of each segment were provided with grooves $\frac{1}{8}$ inch deep and 1 inch apart, to obtain a firm hold upon the wood. Each segment of the tubbing was wedged to the rock, and the space between the tubbing and the rock was filled in with concrete formed of one-third sand and two-thirds cement.

Backcasing the Shaft.—In the foregoing assumed example of a sinking, the method of supporting the sides of the excavation during the sinking to the stone-head, or the "fast," as the firm rock is sometimes called, chosen for illustration, was that system of timbering known as "curbing." This system is generally adopted in the north-eastern coal-field of England, and under ordinary conditions it is probably the most economical. There remains, however, to be described another method, adopted in other localities, notably in the Lancashire districts, which dispenses with wood entirely, except for the walling curbs. This method is known as "backcasing," and consists in employing bricks laid dry, in the place of the wood required in curbing. The mode of procedure in backcasing is briefly as follows:

The shaft is laid out with a diameter 20 inches greater than that required for the permanent walling, and carried down as far as the sides will stand safely. In the case assumed, this depth was 6 feet. A walling curb, similar in construction to those described for the permanent walling, but of larger diameter, and smaller sectional dimensions, the latter being 9 inches × 3 inches, is then laid upon a carefully levelled bed at the bottom of the excavation. A walling of dry bricks, 9 inches, that is, one brick, thick, is built up upon this curb to surface. The bricks used should be of a quality suitable for this purpose, and shaped to accord with the circle of the shaft. The sinking is then resumed with a

diameter equal to the inside of the curb, and continued down another 6 feet. At this depth, the sides of the excavation are shorn back at one part for a width equal to the length of one of the segments of the curb, and a segment of a new curb put in. Punch props will be required to support the curb beneath the walling at this point, from which the underlying bed has been removed. Upon this segment, a new length or course of walling is then built up, and tightly wedged to the first walling curb, so as to afford a good support to the latter. The wedges used for this purpose should be broad and thin, and preferably of fir. An adjoining portion of the sides of the excavation, equal in width to the first, is now shorn back, and a second segment of the curb laid and bolted to the first, and the walling carried up upon this segment and joined by wedging to the upper curb, as before. These operations are repeated until the whole of the curb has been laid, and the circle of walling put in. When this has been accomplished, the sinking is carried down in a line with the inside of the curb through another 6 feet, and the sides shorn back or walled as before upon a third curb. This mode of procedure is continued until the stone head is reached. If the work has been carefully executed, this backcasing will be nearly as strong as the permanent walling, to which it will afford great relief. When the stone head has been reached, the permanent walling is built up inside the backcasing, in the manner already described. Thus, unlike the wooden curbing, the brick backcasing is left behind the permanent walling, whence its name. The support afforded by this system of backcasing is notably superior to that obtained from the wooden curbing.

Sinking through Loose Rock.—In the example chosen for the purpose of illustrating the several methods of procedure in sinking, and in securing the sides of the excavation, the passage through the surface beds was assumed to offer but little difficulty. Frequently, however, these overlying beds of alluvial cover occasion great labour and expense, and demand the application of knowledge and skill. In carrying a sinking down to the stone head through beds of quicksand, or loam saturated with water, an enormous pressure develops itself against the timbering placed to support the sides of the excavation, since the cohesion of the particles of the rock is very little. Hence arises a necessity for very strong timbering. Instead of placing the curbs at intervals apart of 3 feet, as in the example described, it may be impossible to exceed 6 inches, or it may even be necessary to place them in contact with one another. Also the strength of the curbs must be augmented by increasing their dimensions up to a sectional area of 6 inches × 6 inches, and great care will have to be exercised that the wood of which they are formed be perfectly sound and free from defects of every kind. But this excessive pressure is not the only difficulty to be overcome. When, in a bed of sand, the spaces or voids between the grains are filled with water, the cohesion among these grains is destroyed, the film of water surrounding each grain, and the floating action of the fluid present in the interstices, preventing friction. Hence it happens that when an issue is given to the water the grains of sand pass out with it. This fluid character of the sand constitutes a very great difficulty in sinking, because the issue of the sand into the excavation occasions the falling in of the sides and the surface, besides the necessity which it creates of removing an indefinite quantity with the water to be lifted. When the water is under great pressure, this difficulty is immense, and in some cases altogether insurmountable. Thus, at a sinking in the Belgian coal-field recently undertaken, a bed of quicksand was encountered, at a considerable depth from the surface, after passing through the upper beds without difficulty. As soon as this bed was struck, the fluid mass of water and sand rapidly rose in the shafts; so rapidly, indeed, that the sinkers had barely time to escape. As the prospect of successfully contending with the irruption appeared hopeless, the sinking was abandoned.

Numerous examples of a similar nature might be given from the north-eastern coal district of England; some of which were finally dealt with successfully, though at an enormous cost. Sinking through such strata is the most costly and the most uncertain of mining operations, and it should never be undertaken without a careful consideration of all the circumstances of the case.

There are several methods of sinking through quicksand, but the general and most effective method, when the sands exist near the surface, is by piling; that is, by driving planks close together vertically around the shaft, and supporting these internally with curbs. When this method of passing through the loose rock is to be adopted, the shaft must be laid out of a sufficiently large diameter to allow of the successive reductions which will have to be made at each course of piling. To do this accurately, it is necessary to know exactly the thickness of the beds, which must be ascertained from existing shafts in the locality, or if none be available for that purpose, by borings made on the spot. It is, indeed, seldom that the former source of information is sufficient, and therefore preliminary borings may be regarded as generally necessary. As the curbs to be used are 6 inches × 6 inches, and the piling 3 inches thick, every fresh course of piling will diminish the diameter of the excavation by 18 inches. With piles 15 feet long, a fresh course will be required at about every 12 feet, so that the reduction of the diameter in a depth of x feet will be $\frac{1 \cdot 5\,x}{12}$ feet. Thus if the thickness of the overlying water-bearing cover be 100 feet, the reduction at that depth will be $\frac{1 \cdot 5 \times 100}{12} = 12 \cdot 6$ feet; and consequently, if the diameter of the shaft outside the brickwork is to be 15 feet 2 inches, the excavation must be begun with a diameter of 15 feet 2 inches + 12 feet 6 inches = 27 feet 8 inches.

When the sinking has been laid out to the requisite diameter, and the surface soil removed to as great a depth as the ordinary method of curbing will safely sustain, a strong wooden curb, about 6 inches × 6 inches in section, and of a diameter 6 inches less than that of the excavation, is placed in position at the bottom, and perfectly concentric with it. The piles to be used should be about 6 inches × 3 inches in section, and from 10 feet to 15 feet in length; their lower ends should be pointed and shod with iron, to enable them to penetrate the rock, and their edges should be planed true and beveled, so as to form a close joint when placed in contact around the circular curb. These piles are then driven down side by side against the outer face of the curb, care being taken to keep them vertical, that their edges may remain in contact throughout their length. A wooden maul is the most suitable instrument for driving the piles, and where the ground is strong, the latter should be hooped at the head, to prevent them from being crushed and split by the maul. It will not often be possible to drive the piles down to their full length at once; usually about 5 feet will be practically the limit. Supposing, therefore, the piles to have been driven down to this depth, the earth will be taken out from the inside to a depth of 3 or 4 feet or less, according to its strength, and another curb of the same diameter laid to support the piles. As before remarked, the distance of the curbs apart will be determined by the pressure to be sustained. When the support of the curbs has been substituted for that of the earth, the piles are again driven down as far as they will readily go, and the earth excavated from the inside, other curbs being placed to support the piles. These operations are repeated until the piles have been driven down to their full length.

When the earth has been excavated to within, say, 3 feet of the lower ends of the piles, and a curb laid at that depth to support the latter, another curb, 18 inches smaller in diameter than those

previously laid, is placed inside the bottom one, and 3 inches distant from it all round. Into the annular space between these curbs, a fresh course of piles is set, and driven down as far as they will go, and the same operations of excavating, curbing, and driving are gone through as before. On approaching the foot of this second course of piling, another curb, 18 inches less in diameter than those just put in, is laid within the bottom one, and a third course of piling is set in the annular space between them, and driven down as far as they will go. These operations are repeated until the stone head is reached. Piled in this way, a section of the shaft appears as in Fig. 425. When the stone head is reached the wedging curb is laid, and the walling or tubbing erected as quickly as possible. The space between the shaft lining and the piling is filled up, as the walling or the tubbing proceeds, with clay.

The method of piling followed on the Continent differs somewhat in detail from that just described. The piles used are about 3 feet long, from 4 inches to 5 inches broad, and 1 inch thick. Instead of being driven into the ground vertically, as in the method described, they are driven with an outward inclination of 10 or 15 degrees, as shown in Fig. 426. When these piles have been driven in to their full length, the earth on the inside is excavated to a depth of about 2 feet 6 inches, or 2 feet 9 inches; and before the thrust of the earth has brought the piles into the vertical position, a second curb is placed to support them. Around this curb, a second course of piling is driven as before, in diverging directions, and the earth again excavated. If the piles preserve their inclined direction, another set is driven vertically behind the curbs, and the space between the two sets is filled in with bits of wood, as shown in the figure. All systems of piling for passing through water-bearing beds are merely modifications of the two foregoing; and it is evident that these modifications of detail may be extended in an almost unlimited degree.

Water-bearing drift deposits may frequently be passed through by the method of backcasing, if the details of the operations be made conformable to the exigencies of the case. As the sides of the excavation will not stand alone if the height exceed a few inches, curbs will have to be put in very frequently, at intervals of three or four courses of bricks. Also the length of the segment to be bricked at one time must be reduced in a proportionate degree; one-tenth of the circumference, or even less, being as much as may be removed with safety. It will, moreover, be necessary to support the curbs from above in ground of the unstable character we are now considering. This may be effected by means of stringing deals spiked to the curbs and to balks of timber at surface, in the manner adopted for the wooden curbing, already described. Iron rods, however, constitute a better means of suspension than the deals. Such rods should be $1\frac{1}{2}$ inch in diameter, and there should be one to each segment. The usual mode of fixing the rods is to pass them through the bottom curb and through the balk of timber at surface, and to secure them to those pieces by means of washers and nuts. This mode of suspension will be adopted when the bottom of the course of walling has been reached, and the sinking is to be continued in some other manner; as, for example, by means of a drum, when a bed of quicksand is met with. When the quicksand is encountered at a considerable depth, the lower course of walling may be suspended, by means of the iron rods, from an upper course, instead of carrying the rods up to surface.

The method of backcasing, though generally successful in even very wet marl, is inapplicable to quicksands, by reason of the tendency, already pointed out, of the sand to flow with the water into the excavation. When such beds are met with, therefore, it becomes necessary to have recourse to piling, or to the "brick" drum, as it is commonly, but incorrectly, called. In describing the

method of sinking with the drum, which is generally followed in the Lancashire district, we shall assume that a bed of quicksand is encountered beneath some fathoms of cover, and that the back-casing, which has been put in down to this point, is suspended by means of iron rods from balks of timber at surface. The first operation is to construct the drum. This drum, the use of which is to support the sides of the excavation, may be constructed of wood, of wrought iron, or of cast iron. If it is to be of wood, a sufficient number of oak curbs, usually 6 inches in breadth by 4 inches in depth, are placed at intervals of 2 feet, or 2 feet 6 inches apart, until a length is made up greater by a few feet than the thickness of the bed to be passed through. Upon the outside of these curbs are firmly bolted, with their edges in contact, pieces of planking, called "lags." This "lagging" is to take the place of the back sheathing, in the method of wooden curbing, and as the pressure against it will be great, it should have a thickness of 3 inches. It is also important that the edges of these pieces should be truly planed to the circle of the excavation, so that when placed in contact they may bear evenly and fully upon each other; and this equal distribution of pressure may be best attained by limiting the breadth of the lags to 4 or, at most, 5 inches. Constructed in this way, the drum resists like an arch, and it can yield only by the destruction of the material by compression. It will be observed that in this case the arch is composed of the lagging alone, the curbs merely serving as supports to keep the elements of the arch in their places. The true fitting of the joints is also necessary to keep out the water, for the drum is to serve as a short length of tubbing at that portion of the shaft where the quicksand occurs. Around the bottom of the drum, and on the outside, a plate of iron, about 2 feet broad, is bolted so as to project half its breadth beyond the lower end of the drum. This plate is called the "leader," and its use is to enable the drum to cut its way into the sand or soft clay. The lower edge of the plate should be made sharp, to allow it to fulfil its purpose more effectually.

When the drum is thus prepared, it is lowered into the shaft and brought to rest with its cutting edge upon the bottom of the excavation. To give the drum weight, the spaces between the curbs are filled up with brickwork. The sand is then carefully excavated from the inside of the drum, which, deprived thus of its support, sinks through the bed, the leader cutting its way down as the resistance is diminished by the removal of the sand. Sometimes the friction against the sides of the drum will cause it to stick, notwithstanding the weight of the bricks inside. In such cases additional weight is applied in the following manner. Four pieces of timber, two bearers and two cross-pieces, are laid upon the bottom curb, so as to leave a rectangular opening in the middle, and pieces of board are laid upon these timbers around the central opening. Upon the staging thus constructed, bricks are built up to the top, or as far as may be needed to give the requisite weight. It is of essential importance that the drum be placed perfectly vertical in the shaft, and that it be kept in that position during the sinking, for if it once lose its verticality it is almost impossible to rectify the evil. When the drum has sunk through the sand, and a few feet into the clay beneath to form a water-tight junction, the sinking may be resumed in the usual manner, by backcasing to the diameter of the curbs inside; for it will be observed that the drum, like the piling, will reduce the diameter of the excavation by 18 inches. When the permanent walling is put in, it will be built up inside the drum, which merely serves as a backcasing. In most cases, however, the curbs may be recovered.

Though a wooden drum may be run to a much greater depth than a course of piles can be driven, it is urged as an objection to this drum that it reduces the diameter of the excavation to the same extent as the piles. To remedy this defect, wrought iron, in the form of $\frac{1}{2}$-inch boiler plate,

has been substituted for the wood. But the liability of these to collapse, owing to the absence of inside staying, renders them far more objectionable than the wooden drums. It is, moreover, extremely difficult to keep these drums in the vertical position, or to increase their weight, if necessary. On the other hand, the friction between them and the rock is less. But these defects may be removed by the adoption of cast iron. Drums made of this material are cast in segments, in the same manner as the ordinary tubbing, but with the flanges and strengthening ribs on the inside; for it is essential that the outside of the drum be smooth to allow it to sink through the sand. Such a drum will seldom need to be weighted, and the reduction in the diameter of the excavation occasioned by it will not be more than half that due to the wooden drum. Besides this, a well-constructed cast-iron drum may be run in so as to constitute a portion of the permanent lining of the shaft, as a short length of tubbing, in fact. When this can be accomplished, the cast-iron drum will afford the most economical means of passing through a bed of quicksand.

The following example of sinking through a bed of quicksand by means of the cast-iron drum is worthy of careful consideration. In this instance the work was well designed and skilfully executed in the face of great difficulties; and as Mr. H. Bramall, of Rainford, to whom both the design and the execution of the work are due, has briefly and clearly described the operations in a paper read before the Manchester Geological Society, we quote the following as given by him:

"The pit referred to is the No. 9 Pit, of the Rainford Colliery, and is situate about 11 miles from Liverpool, on the Lancashire and Yorkshire Railway. The cover, or drift, here consists of

	Feet.	Inches.
Soil	1	6
Marl	34	6
Loam	15	0
Wet gravelly clay	16	6
Quicksand	21	0
Gravelly marl	3	0
Total	91	6

"This pit was commenced in September 1860, with a diameter of 19 feet clear, and was sunk on the usual Lancashire plan of brick-casing, but owing to the slovenly and careless manner in which the work was done, the side of the pit was pushed in by the pressure at a depth of 17 yards; and to save the pit, a ring, 13 feet inside diameter, was laid on the bottom, and a casing of 6-inch brickwork brought up nearly to the surface, the space between the two casings being filled with ashes, as shown in the upper part of Fig. 427. This casing also was put in in a very negligent manner, and proved afterwards a source of considerable trouble to us, the chief aim having apparently been to put in the greatest number of yards in the least time, and for the least money, without a care or a thought about the quality or the safety of the work, or of what was ultimately to be done with the pit. Indeed, the pit was then abandoned, and another commenced at a distance of 40 yards. Here the top, though troublesome, was not nearly so bad, and was passed without very much difficulty, by carrying the pit down in the usual way for 12 yards in the marl, and afterwards running two wooden drums. When I undertook the management of the colliery in October, 1861, I found they had just passed the sand in this new pit, and having found a suitable bottom, I laid a wedging ring, and brought up cast-iron tubbing to stop out the sand-feeders. Having thus secured this pit, I turned my attention to the No. 9 Pit.

"We first proceeded to lay two balks, Fig. 427, across the pit, resting on frames *b b* at each end, and across these two other balks *c c*, also resting on frames *d d*, the frames standing on a number of short planks *j j*, placed crosswise, to spread the weight and prevent the frames from sinking into the ground, as the place had formerly been a marl hole, and having been filled up with loose materials, it was very soft. On the crossed balks, were erected the pulley frame and banking stage. Sinking was then resumed on the backcasing plan, taking out very short segments at a time, and putting in rings at every 18 inches, which distance, as the ground became worse, was reduced to 9 inches, or three courses of bricks. We thus carried the work down within a yard of the sand. The whole of the rings were then hung by spiking 2-inch battens along the face of them and to the balks above. The lowest ring was doubled, and three strong bearers placed upon it and across the pit, so as to form a triangle, on which a ring was laid perfectly level to form a stage on which to build the drum, and at the same time allow the water to be wound out of the pit.

"It was my intention to use the drum as part of a length of water-tight tubbing, with which I purposed to stop out the sand-feeders. The drum was cast in segments, and was 12 feet in diameter outside; each segment was 2 feet deep, and twelve of them formed a course. They were made as shown in Figs. 428 to 430, with the brackets and flanges *inside*, so as to leave the back perfectly smooth, in order to receive the least possible amount of frictional resistance from the ground to be passed through. The segments were fastened together by $\frac{3}{4}$-inch bolts, $\frac{1}{2}$-inch sheeting being put between all the joints. The lowest course of segments had riveted on the back a leader *a*, Figs. 428 and 430, which was simply a plate of iron, 1 inch thick in the upper part, and sharp on the lower edge, so as to cut its way through the ground. The corner or shoulder formed by the leader and lower flange of the bottom course of segments was filled up by a beveled ring of wood *b*, Fig. 429, to lessen its resistance to the passing downwards of the drum; this was afterwards removed to allow of segments being bolted below the drum, as shown by the dotted lines in the figure.

"The lower course of segments, with the leader attached, *f*, Fig. 427, was then placed upon the ring platform at the bottom of the pit, and fourteen additional courses of segments built upon it, so as to form a drum about 10 yards long. Six sling chains *g g* were attached to the third flange from the top, $\frac{3}{4}$-inch chains carried from these to the surface, and coupled to screws *h*, 2 inches in diameter, passing through the before-mentioned balks. All preparations being now made, we proceeded to lift the drum by means of the screws, and take out the platform ring and bearers, on which up to this time the drum had been resting. It was then lowered upon the clay, into which it at once sunk. On proceeding to take out the clay, the sand blew up into the pit with considerable force. The screws were slackened and the drum allowed to sink very gradually, the utmost care being requisite to keep it upright. The sand was sent out of the pit, keeping the leader 3 feet below the pit bottom. At the end of a hundred and eight hours from its first entering the clay, the drum had sunk 22 feet. Here it began to stick, and we were compelled to weight it. We constructed a scaffold near the bottom of the drum, with a 6-feet square hole in the centre, leaving room enough between the scaffold and the bottom of the pit for the men to work in. Bricks were then built upon this scaffold. On taking out a little more sand, the drum began to move, and sank 2 feet 2 inches in 12 hours, passing through the sand on the rise side of the pit, and entering a gravelly or stony marl. We again added weight, and ultimately forced it 3 feet through the marl, until it lodged upon brown rock on the higher side. The drum had thus run 27 feet from the commencement.

"The most difficult part of the operation now presented itself. The dip was found to be very

severe, and while the drum on the one side rested on brown rock, rendering it quite impossible to force it any farther, on the lower side of the pit the leader had not entered the clay more than 6 or 8 inches. On attempting to remove the clay, a rush of sand and water took place, which speedily drove us out of the pit. In order to overcome this difficulty, we took a number of piles *k*, 6 feet long, 6 inches wide, and 3 inches thick, made very sharp at the point, and drove them longitudinally into the side of the pit, close together, under the leader, and as far round the pit as could be done. Over these were driven circle wedges *m* of 1-inch deal, and about 1 foot wide. These kept back the sand sufficiently to enable us to bare the rock and get in a few segments on the deep side of the pit, bolted to the lowest course of the drum. We then took out the rock so as to allow of this course being completed round the pit; and having sunk a couple of feet, we bolted another course to the last one. We now felt perfectly secure, and went on sinking and seeking a suitable place for a wedging ring. This we found in a close brown linsey, at a distance of $13\frac{1}{2}$ yards below the last segments. Here we laid a wedging ring *o*, and brought up tubbing till we joined that forming the drum, taking the precaution of placing an escape pipe in the closing course. Tubbing was also placed upon the top of the drum until the surface-feeders were outset, when the whole was wedged. As the shaft is intended for an up-cast, we have since lined the tubbing with brickwork, as shown in the lower part of Fig. 427."

In Germany and in Belgium, a method of sinking through quicksands is adopted very similar in character to that of the drum used in England. In this method, a cylinder of masonry is substituted for the wood or iron of the drum, and the masonry is made to rest upon wooden curbs, the bottom one of which is furnished with an iron leader, to enable it to cut its way through the sand. The following description of this cutting curb and walling is given by M. Ponson, in his work on 'Coal Mining in Belgium.' It may be remarked that a similar method of sinking a shaft was adopted by Brunel in excavating the Thames Tunnel:

After having made secure, by means of sheet-piling, a square excavation *a b c d*, Figs. 431 and 432, from 6 to 10 feet deep, and sufficiently large to allow the workmen space in which to carry on the work which they have to execute, the sinking is continued of a circular form to a depth of about 6 feet, the diameter of the excavation being from 2 feet to 2 feet 6 inches greater than that required for the shaft and its walling. This latter excavation *b e f c* serves to facilitate the vertical descent of the masonry. The sides in this case do not need to be supported, as they are only left a few hours unprotected, and slips, under these conditions, are to be but little feared near the surface of the soil.

A hollow cylinder of wood A B is prepared beforehand, the base B B′ of which is a platform, or circular curb formed of three rings. These rings are of oak, and are from 2 to 3 inches thick. They are placed one upon another, and are doweled and firmly bolted together. The upper ring has an external diameter equal to that of the masonry, and a breadth equal to its thickness; that is, about 18 inches. The middle ring projects beyond the first about 2 inches, in order to leave exposed an outer edge into which is cut an annular groove 2 inches deep and 1 inch broad, designed to receive the ends of the planks which envelop the column of masonry. The lower ring is slightly inset to receive a steeled leader, three-quarters of an inch thick and from 3 to 4 inches deep, sharp on its bottom edge, and inclined outwards in such a manner that its lower edge projects about three-eighths of an inch, experience having shown that this form is the most suitable for enabling the cylinder to penetrate the soil.

This platform-curb, which is represented in the figure as having already descended to a certain

depth, is placed in the first instance at the bottom of the excavation *e f*, and vertical boards, 12 to 20 feet in length, 8 or 9 inches wide, and about $1\frac{1}{2}$ inch thick, are placed side by side, and inserted by their lower ends into the annular groove in the centre curb or ring. To complete the cylinder, two curbs, each formed of two rings, are introduced, the one A A′ at the upper part, and the other C C′ at the centre of the vertical boards. On the upper surface of each of these are placed horizontal cross-pieces *m m′*, about 6 inches square, by means of which the superposed cylinders are bound together. This hollow cylinder serves to contain the masonry, and also as a centering in which to construct it; it also greatly favours the descent of the walling by preventing the great friction which would take place if the latter were in contact with the soil.

The masonry being erected, the circular space *b e f c* is filled with the débris previously extracted, care being taken to guide the cylinder from the commencement of the operation and to ensure its descent in a truly vertical direction. These preliminary operations having been completed, the apparatus is made to penetrate into the sand, by digging in the centre of the shaft a cavity N, in the form of a reversed truncated cone. The sand will then generally, under the pressure of the masonry, slide from under the platform and rise up in the centre of the shaft, allowing the cylinder slowly to descend. If, however, it remains firm, the hole should be enlarged and its form changed from that of a cone to that of a cylinder; the soil will then offer less resistance to the pressure of the masonry. If these means do not succeed, two workmen, placed back to back, cut holes under the platform curb on opposite sides. Lastly, the ground beneath the leader is completely cut away for a depth of 18 inches or less, care being taken not to shear one side lower than the other, as this would cause the cylinder to descend obliquely. In this latter case, the whole of the curbs should first be bound together, in order to strengthen the masonry and to bind it into a single mass, thus preventing it from separating into two parts, of which one would descend alone, whilst the upper part, retained by the pressure of the soil and the friction, would remain suspended. It is for this purpose that the cross-pieces *m m′* are provided. These pieces are held by iron bars *n n*, the upper ends of which pass through them and are fastened by nuts, the lower ends being bent at right angles and passing under the curb below. Finally, if the weight of the masonry is insufficient, the cylinder is weighted with stones, old iron, or other heavy substances, until it sinks.

When the upper part of the cylinder reaches the level of the bottom of the rectangular excavation, it is lengthened in the following manner: The upper ends of the planks *g i* and *h k* are cut off at an angle, and nailed to the lower ring of the curb, other planks *g p h q*, cut in the same manner, are placed on the first, and nailed to the ring A A′. Two curbs are then placed, as in the first length, one at the top and the other in the centre of the planks; the cross-pieces are placed in position, and fixed, the masonry is erected, the iron tie bars are inserted, and the whole again is made to descend in the manner described. These operations are repeated until the solid rock, or some other impermeable bed, is reached.

During the operation, the master sinker, by carefully observing the plumb-line, will immediately perceive if the cylinder deviates from the vertical direction; and as this evil, once begun, increases very rapidly, he will have to apply an immediate remedy.

The causes of the oblique descent of the cylinders are often a slight slip, or a more rapid fall of the soil on one side than the other; sometimes it may be attributed to an unequal pressure, caused by an inclined stratification, or by encountering a quartzose pebble, &c. It is in the first few yards of the excavation that these accidents are met with most frequently. In any of these cases, the

miner rapidly cuts away the soil on the side opposite to the slip, and props the side of the wall which has a tendency to advance too fast. He also suspends the whole by means of iron rods, the lower ends of which are furnished with broad straps, to pass under the platform curb, the upper ends terminating in long screws, which pass through balks of timber, placed across the mouth of the shaft. By means of these screws, the masonry may be held in position, or dropped at pleasure. Ropes or chains are also employed, and fastened by one end to stakes, firmly driven into the ground, the other end being suspended in the shaft, and fastened to the cylinder. These arrangements also serve to prevent the too rapid, although vertical, descent of the whole.

It is always prudent to bore frequently under the platform curb, in order to discover any pebbles that may exist, as at G, Fig. 431, as these would either blunt the cutting edge of the leader, or cause the cylinder to incline to one side. When this circumstance happens, the walling will have to be supported. In order to do this, the miner places the cross bearers *n*, and under them the shores or props *o o*, which are prevented from sinking into the earth by having their feet placed upon the frame *v*, which rests upon the soil. Then he excavates all round and under the stone which forms the obstacle, and removes it. If a bed of clay were met with, interstratified with the alluvial sands, the same method of procedure would have to be adopted.

In the Anzin coal district of France, beds of quicksands, locally known as "torrents," are met with below the chalk marl, at considerable depths from the surface; generally from 70 to 80 yards. The method of passing through these beds usually adopted in that locality is the following simple one: When the excavation has been walled down to near the quicksand bed, a wooden curb, of the same diameter as the shaft, is wedged against the rock beneath the walling. The use of this curb is to afford a point of support against which screws may be set during subsequent operations. Besides the wedging, two bearers are placed across the shaft above the curb, and firmly fixed into the rock, to prevent the curb from being forced up by the pressure to be brought against its lower side. An oak curb, of the dimensions of those used for tubbing, is then laid upon the sand, at the bottom of the excavation, and beneath the wedged curb. This oak curb is provided with a cutting edge, by beveling the under side, that is, the outer face is made twice the depth of the inner face. Around the outside of the curb, an iron plate is screwed to form a leader, the heads of the screws being countersunk, to avoid projections on the outside, and the lower edge of the plate being allowed to extend an inch beyond the wood. The segments of the curb are joined by tenon and mortise, and the joints are strengthened by iron straps. Pressure screws, to be applied after the manner of a lifting jack, 4 inches in diameter, and from 8 feet to 10 feet in length, are then set upon the cutting curb, and made to abut against the wedged curb placed above for that purpose. When the cutting curb has been got perfectly level, and the screws have been tightened, the former is pressed down, by turning each of the latter about one-third of a revolution in succession. As soon as the sand appears behind the descending curb, and on a level with its upper side, means are taken to prevent it from flowing over into the excavation, by driving in pieces of fir sheathing, sometimes preceded by straw bands. The jack screws are then removed, and a second tubbing curb, of ordinary construction, is laid upon the first, and bound to it by means of vertical iron straps, nailed on simultaneously at several equidistant points. The screws are then replaced, and the tubbing is again forced down, until the second curb is on a level with the sand. A third curb is then placed upon the second, and strapped to it in the manner described; the sand displaced by the curb is removed, and the three are again forced down. These operations are repeated, until the lowest, or

cutting curb, has entered the clay beneath, when the shaft, throughout the length occupied by the sand bed, will have been securely tubbed. Great care is needed to prevent the tubbing from deviating from the vertical during the descent, and to facilitate its even motion. Pebbles are picked out from beneath the cutting edge by means of tongs or other suitable tools. When the clay has been reached, the sinking is carried on in the usual manner, until a foundation for a wedging curb is met with, upon which the wood tubbing is carried up to the cutting curb. The beveled edge of the latter, with its iron leader, is then cut away in portions, leaving its under side level, and a curb of suitable thickness is inserted, to join and complete the tubbing.

Another method of sinking through the upper water beds of this district merits attention; this method partakes of the character of the preceding, and of that of piling. The excavation having been begun of a sufficient diameter to allow of the subsequent necessary reductions, is carried down till the water is met with, when the bottom is levelled, to receive a wooden curb. This curb, which is generally polygonal in form, is 4 inches in breadth, and 12 inches in depth, and it is strengthened at each of its angles with iron straps. Behind this curb, piles are set, and driven down vertically side by side, so as to form a close joint. These piles are from 6 feet to 7 feet in length, 4 inches broad, and 1 inch thick, and they are first driven down about half their length. The sand or marl is then removed to a depth of 12 inches, which is equal to the depth of the curb. A second and similar curb is laid upon the first, and the two are driven down, by means of mauls, to the bottom of the excavation. The earth is again removed to a depth of 12 inches, a third curb is laid upon the second, and the whole are driven down with the maul, as before. During these operations, the piles are kept in advance of the bottom curb. If the curbs become fixed by the pressure against them before the foot of the piles is reached, the remainder are put in from below. When a tubbing of curbs has been put in, in this manner, to nearly the length of the piles, a curb of the same sectional dimensions, but of 10 inches less external diameter, is laid within those already fixed, and on a level with the lowest; and a second series of piles is driven in between the inner and the outer curb. These piles are not driven in to their full length, but are left to stand out about 12 inches, so that they may be nailed to the first series of curbs, should the forcing down of the second carry the piles with it. This second series of curbs is sunk in the same manner as the first, and the same operations are repeated for all the subsequent series needed. This method has been successfully adopted in numerous instances.

The foregoing are the methods adopted in different localities for sinking through water-bearing strata. Of course, each of these is subject to modifications, and some modification will always be necessary to adapt the system to the exigencies of the case. In shaft-sinking, where the conditions are ever changing, much must necessarily be left to the judgment and the invention of the engineer in charge, who will have to adapt the means at his disposal to the end to be attained in a manner that is most in accordance with the circumstances in which he finds himself placed. But to do this successfully, he must at least possess a knowledge of the various methods practised under different conditions in different localities, so as to be able to combine and to modify them according to the requirements of the case in hand.

The Kind-Chaudron System.—Within the last few years, a system of sinking shafts through water-bearing strata has been introduced, and adopted with marked success on the Continent. This, which is known as the Kind-Chaudron system, consists in boring out the shaft from surface by means of apparatus similar in character to that used for prospective borings. A detailed descrip-

tion of the Kind-Chaudron system was given by E. Bainbridge, in a paper read before the Institution of Civil Engineers, in 1871; and the system was again described later by Warrington W. Smyth, in a paper contributed to the North of England Institute of Mining Engineers. From the latter paper we extract the following:

"In the year 1849 it was proposed by the eminent master borer, Kind, to bore out pits by apparatus placed at the surface of the ground, and of the same character as that employed for Artesian wells; to excavate the rock without removing any of the water, and on arriving at firm ground below the watery measures, to lower down a suitable lining or tubbing. Several shafts were during the next few years sunk by him on this principle, but it did not appear on these first trials that any notable economy was obtained, or that the lining could be so introduced as securely to tub back the water. At the London International Exhibition, in 1862, M. Chaudron, a Belgian engineer, who had joined Mr. Kind in bringing forward an improved process, exhibited a segment in full size of a kind of gland, *boîte à mousse*, or moss-box, which he had devised for the purpose of forming an effectual water-tight joint in the place of the ordinary wedging curb; and the details which he published in the 'Annales des Travaux Publiques de Belgique,' of several pits sunk by this method, seemed to give assurance of its importance. In Paris, in 1867, the colliery company of the Hôpital St. Avold, in the department of the Moselle, exhibited the actual tools with which Messrs. Kind and Chaudron had just succeeded in boring for them two large shafts, one of them about 14 feet in diameter, and fixing under water a thoroughly water-tight tubbing, on foundations at depths of 521 and 523 feet from the surface.

"The coal measures were here overlain by several hundred feet in thickness of the very watery strata of the Grês de Vosges, a part of the new red sandstone series. Various attempts made by different mining companies to sink to the coal measures had already cost, up to the year 1858, no less than 840,000*l.*, and as the ground was confessedly of a very difficult character, and these two pits were put down for a sum not more than one-third of what it was estimated they would have cost by the ordinary method, it was evident that a remarkable step in advance had been taken, and that the combined method of these two engineers now stood on a firm and practical footing.

"Having learned that a sinking by the new system was in progress in Belgium, in a district that offers peculiar difficulties on account of the water-bearing strata to be passed through, the author went over and inspected the process, and informed himself concerning the details of the operations.

"The coal-field between Mons and Charleroi is overlain uniformly and somewhat irregularly by strata of the cretaceous and tertiary periods, which thin out and allow the coal measures to crop to the surface at Bois-le-duc, an extensive and ancient work east of the station of La Louvière, but which become thicker to the west and south of that station, till they attain to several hundred feet over a large area; and at Ghlin, near Mons, have been proved by borings to be 230 metres, or 754 feet thick. These beds consist in great part of sands, marls, and chalk, with occasional bands of massive flints and loose or running sand; and with water generally extremely abundant until the excavations reach certain of the more solid lower beds of the cretaceous series, the so-called *dièves*, or the *tourtia*, or have penetrated to the coal measures themselves, when scarcely any addition to the water is expected.

"The pits now in process of sinking *à niveau plein*, at 'full level,' or under water, in the concession of Maurage, are situate in a virgin district on the north rise of the basin, and a short mile distant on the west from the railway station of Bracquegnies. At this latter place, the older

pits, called St. Alexandre, were completed in 1847, after enormous difficulties due to water and quicksands, which were overcome by the perseverance of M. Delaroche; whilst the new plant, called St. Alphonse, farther south, was fortunately commenced at a much more favourable spot, but nevertheless cost a sum of 2,000,000 francs, or 80,000*l.*, inclusive of plant.

"At Maurage, the thickness of the overlying aqueous beds is known from common borings to be much greater, and the foundation of the iron tubbing of the shafts is fixed at 194 metres, or 636 feet, below the surface. A branch line of private rails leads to the pit, which, with all the apparatus connected with them, are, as usual in Belgium, under cover. The principal feature of the exterior consists of two wooden towers, about 60 feet high, containing the pulley frames for the boring operations; and between the two come in the engines, the smithy, and the office; whilst closely adjoining is the fast-increasing store of tubbing rings, being proved as they are delivered from the founders, in readiness for dropping when the work is a little farther advanced.

"At each shaft the men employed in the sinking, four or five in number, stand on a working floor 5 metres below the surface, the shaft being here 5·75 metres, or close on 19 feet, in diameter, but being narrowed immediately below to 4·70 metres, or 15·4 feet, of which size, and protected by bricking, the shaft is carried down to the water-level, about 30 metres. Below that point it stands full of water, unlined, and is, in fact, a colossal bore-hole.

"The excavation of these large pits of 14 feet diameter is effected by at least two successive stages. At first, a cylindrical hole of about 4 or 5 feet diameter is bored, and this is usually kept at the least 10 metres farther advanced than the wide or full-sized pit to which it is enlarged by the second or third operation.

"The cutting of the ground for excavation is by the same kind of means in both stages—the central and the enlarging, whilst the removal of the débris is different. In each case the cutting-tool, *trépan*, Figs. 433 to 439, consists essentially of a horizontal wrought-iron bar, to the under surface of which are attached steeled teeth, so placed that as the bar is rotated round the central axis of the pit, each tooth, in falling with the bar through the requisite length of the stroke, generally a quarter to half a metre, cuts for itself an annular portion of the bottom of the shaft. The trépans, both large and small, for, of course, they are worked only at separate times, are lifted and turned by the same rods, these latter being of pine, 20 centimetres square and 18 metres long, and connected as in common boring by male and female screws. Care is taken to preserve the whole strength of the pole; and the elasticity of the wood, with its buoyancy in the water, are found, as in most deep borings in America and Europe, to give great advantages over iron rods.

"The lift is effected by means of a simple lever placed at the level of the surface of the ground, to one end of which the rods are attached by a strong flat chain, whilst near the other end it has a direct connection with the piston-rod of a steam cylinder of $39\frac{3}{8}$ inches in diameter, and 40 inches length of stroke, placed below the beam; so that the simple admission of steam above the piston depresses that end and raises the rods and cutter, which then fall by their own weight. This striking beam is 23 feet long, 11 feet on the side of the borer, 12 feet on the side of the engine; it is formed of two superposed logs of wood, the upper one of pine, and strengthened on each side by a stout plate of iron. Beneath the suspension chain is a lengthening screw, and below that a very strong swivel, by means of which the rotating movement is given to the rods and cutter. The upper piece of rod has, as usual in boring, eyes for the insertion of cross-bars, by which the actual turn is given at each stroke by the workman standing on the wooden flap doors which close all the

shaft, except the central rod-hole at the level of the working floor. The smaller trépan, Figs. 436 to 439, is differently constructed, according to the nature of the ground it is intended to cut. When engaged with soft material, the *lame* or bar to which the teeth are attached is suspended by a fork of wrought iron ; but when hard rock has to be encountered, such as the massive flint at the time of our visit, it is forged in a single piece, and weighs 8000 kilogrammes, or about 8 tons. The working drawings, kindly supplied to us by M. Chaudron, will sufficiently show the details of construction of this powerful instrument, which is capable of advancing, in ordinary ground, $2\frac{1}{2}$ metres, or above 8 feet per day. The teeth, which are well steeled, fit into sockets in the lame or main bar, and are additionally secured by a pin, which is readily driven out when the teeth have to be sharpened or renewed.

"When the cutter has done its work for some hours, usually at the rate of nine to ten strokes per minute, sometimes at about twenty, it is raised by bringing into action a small capstan engine, with a flat hempen rope of $14\frac{1}{4}$ inches wide by $2\frac{3}{8}$ inches thick, and the successive unscrewing of the rods in the usual manner. The hole is then cleared by means of a shell, sludger, or pump, *cuiller*, a sheet iron cylinder of some 6 feet in length, with two valves in the bottom, which is lowered and raised by the rods.

"The large cutter or trépan, Figs. 433 to 435, which weighs in all 16 tons, is similarly formed of a lame or bar of wrought iron, having teeth attached for that portion of its length which exceeds the diameter of the small pit; and it is guided below by a cradle of iron bars, which fit loosely within that smaller diameter. The teeth are so formed and set that they always cut the bottom of the shaft into a sloping surface, so as to allow the fragments to roll into the smaller pit, and there they are caught in a sheet-iron bucket which is previously lowered into it. The rate of progress, in ordinary ground, when all is going well, is about 1 metre, or 3·28 feet, per day, but in hard rock this is reduced to a quarter of that amount.

"In order to obviate the tremendous vibration which would be imparted to the rods by implements of this unusual weight, a special joint is necessary, in order to detach to a certain extent, from the mere suspension rods, the heavy rod and the cutting tool, which together are 36 feet long. The ingenious 'free-falling' apparatus, devised by Kind, and found so applicable in bore-holes of moderate diameter, was proved in former experiments to be unsuited to these great dimensions, and a slide piece, *glissière*, of great strength is now always applied, in a manner analogous to the "jars" commonly used in the oil borings of America.

"The vertical position of the boring rods throughout the sinking process is additionally secured by guides attached to the upper part of the instrument. In the smaller trépan, these are formed of two strong iron bars set at right angles, and having teeth at their extremity, which slightly enlarge, and at the same time smooth down the sides of the bore-hole. With the large trépan, one cross-piece only is rigid; the other one at right angles to it is hinged on both sides of the main rod in such a way as to be lowered or raised during the shifting of tools, through a comparatively narrow opening in the working floor. It is afterwards, by aid of ropes wound on small windlasses, brought into position when the tool reaches its proper position for working. The guide then forms a cross, through the central opening of which the rod of the boring tool slides freely up and down.

"The most remarkable part of the operation is the fixing of the tubbing, Fig. 440, without the use of pumping engines, in such a manner that it shall securely dam back the water in the measures sunk through. The lowermost ring of the tubbing is, like all the upper portion, cast in a single piece.

Its bottom flange A, which comes to rest on the bed or seat cut in water-tight ground, is turned outward, its upper flange B inward. Upon the lower flange and all round the ring a wall of well-picked moss C is packed tightly against it, and secured in its place by a net placed at the back of it. To aid in the forcing of the moss against the side of the shaft, small sheet-iron springs D D are placed above and below, as seen in the drawing, which have the effect of giving the pressure a definite direction. On the moss cushion rests, by a flange also turned outward, the next ring E, large enough to slide down outside the bottom piece, as soon as the moss is pressed down by the weight, and upon this sliding piece the ordinary rings of tubbing are built. Each flange is planed, and between them a ring of sheet lead of one-eighth of an inch thick is laid, which, after screwing up by the bolts, is beaten on both sides with hammer and chisel. The tubbing is of extra thickness, and each ring, generally about $4\frac{1}{2}$ to 5 feet high, is tested on the spot by hydraulic apparatus. The lowermost simple ring is $2\frac{5}{8}$ inches thick, and weighs $11\frac{3}{4}$ tons. The upper ones are made gradually lighter, but the total weight of the tubbing to be lowered in each shaft is no less than 800 tons. In order to facilitate the gradual lowering of this enormous weight, by means of the six rods and screws used for this purpose, a diaphragm or false bottom F is attached by screw bolts near the bottom of the tubbing, which causes it to float on the water. A centre equilibrium tube G passes up the shaft, and through cocks, placed at intervals, allows of water being poured into the middle of the tubbing in such measure as may help to aid its descent. In this way they contrive never to have a greater weight than 40,000 kilogrammes, or 40 tons resting on the suspension rods.

"When at length the moss-box, hanging by light rods H from the flange of an upper ring, comes to occupy its position on the seat or bed, the weight of the tubbing above begins to bear on the moss and squeezes it down and against the sides in such wise as to form a thoroughly water-tight joint.

"For additional security, the annular space between the rings and sides of the pit is filled, by means of spoons discharged by pistons, with *béton* or concrete, which is allowed to consolidate before the water is drawn out of the interior of the pit. Much, of course, depends on the perfection with which the seat of the moss-box is cut and smoothed; and for the purpose of ensuring its proper condition, a gigantic pair of pincers, *grapin*, I, with arms on the principle of a lazy-tongs, is lowered with and underneath the whole of the tubbing with a rod passing up through the central or equilibrium pipe. The ends of this tool can, by working the rod up and down, be made to expand to the full size of the shaft, and brought together so closely as to pick up fragments of stone or iron which may be lying on the bed of the shaft, and then in its contracted form it may be passed out of the way into the smaller central shaft.

"The water being, after the setting of the béton, pumped out of the pit, the false bottom is removed by unscrewing the bolts which attach it to a flange, the moss-box foundation is examined; and to make everything thoroughly safe, a lower seating is cut a few feet deeper, a wedging curb put in by hand in segments, and a length or two of tubbing built up to the moss-box, and securely wedged against it. The shaft is then free from water and ready for further sinking by the ordinary methods."

Journal of the Sinking.—It is important that a register be kept of everything of importance that occurs during the sinking of a shaft. In this register or journal, an intelligible and a full description of the strata passed through should be given, so that the "section" thus recorded may be of use sub-

sequently. The best manner of describing strata was pointed out and explained in the chapter devoted to boring. But it is not sufficient to illustrate the section only. The journal should be a record of all the important details of the work of sinking, and any observations that may subsequently possess a practical value should find an entry in its columns. If this were generally done, the published sections or records of sinkings would have a value which at present they seldom possess, and by affording, at the moment when required, precise information concerning past experience, such records would tend in no inconsiderable degree to lessen the hazardous and costly nature of sinking operations. The following arrangement of the page may be taken as a guide in preparing the journal, though it is by no means intended to confine the information to the subjects here indicated. The wider and more detailed the information, the greater will be the value of the record. That which we have suggested should be considered as indispensable in every case; more may profitably be added:

JOURNAL.

Sinking executed at in the County of . On the Estate of .

Begun May 1, 1874. Completed June 5, 1875.

Date.	Description of Strata.	No. of Specimen in Case.	Organic Remains.	Thickness.	Depth from Surface.	Angle of Dip.	Time occupied in passing through.	Quantity of Water met with.	Nature and Dimensions of the timbering used.	Nature and Dimensions of the Shaft Lining.	Remarks.

Cost, and Arrangements with Contractors.—There is probably no kind of work that varies so widely in cost as shaft-sinking. The conditions under which the work has to be executed are so liable to change from one spot to another, even in the same locality, that no estimate, not even an approximate one, can be given that shall be generally applicable. But a rough approximation may be arrived at of the cost of the important operations of timbering, walling, tubbing, and bratticing, by taking an average from a number of sinkings, from 13 feet to 15 feet diameter, executed under different conditions. Thus obtained, the cost of the wooden curbing generally adopted in the north of England will be from 4*l.* 10*s.* to 5*l.* a yard; and that of the backcasing commonly employed in the Lancashire district will be about the same. The cost of the permanent brick-walling will be from 5*l.* to 6*l.* a yard, and that of stone walling from 7*l.* to 8*l.* a yard. The cost of cast-iron tubbing is more difficult to arrive at, by reason of the greater variations that occur in the price of the material; but taking a general average, it may be stated roughly as varying between 30*l.* and 40*l.* a yard. The cost of the permanent bratticing will be from 2*l.* to 2*l.* 10*s.* a yard. These prices include all labour of preparing the materials, and of putting them into the shaft.

Sinking is usually done by contract, the contractor agreeing to provide all labour and material, or a certain portion of the material, and to sink and line the shaft for a fixed price per yard or per fathom. This price will be determined according to the evidence of the nature of the strata to be passed through, afforded by boring or by any other available and trustworthy source. The cost of sinking through water-bearing strata is so uncertain that this portion of the sinking will not be undertaken by contract, but will be done by day work, according to a scale of charges previously

agreed upon. Generally, the sinking to the stone head will form a separate contract. In drawing up the terms of a contract, the work to be performed should be precisely indicated and clearly described, so as to avoid causes of subsequent disputes. The chief points to be clearly defined are, the diameter of the shaft when finished; its depth from surface to floor of seam, and to bottom of sump; the nature of the lining, and the dimensions and quality of the materials of which it is to be composed; the supply of all the material and machinery required in sinking,—if a portion is to be supplied by the owner, such should be clearly stated; the arrangements to be adopted when large quantities of water are met with; the nature of the bratticing to be put in; the number of sinkers to be employed in the shaft; and the number of hours in the week during which operations may be suspended. In addition to this, there will be required the customary clauses respecting the periodical measurement of the work, and the control to be exercised by the engineer or viewer. It will also be well to require the contractor to furnish the engineer, as the sinking proceeds, with proper samples of all the beds passed through.

Shaft Fittings.—When the shaft has been sunk to the required depth, and lined throughout, it remains to prepare it for the various purposes which it is intended to serve. The permanent brattice must be put in, and the shaft divided into compartments for the work of winding and pumping. Figs. 441 to 445 show the various ways of dividing a shaft for these purposes. The fitting up of each of these compartments will be treated of in the chapters devoted to winding and drainage. In these chapters also, the construction of the head-gear will be described and illustrated. It will be necessary to fence the shaft mouth, in compliance with the law on this matter, to prevent accidents, and the laying out of the surface immediately around the mouth of the shaft, or the pit-bank, as it is technically called, will demand attention. These matters will be fully considered in the chapter devoted to surface works. The bottom of the shaft, which part is known as the pit-eye, must be laid out to receive the loaded tubs as they arrive from the workings, and to despatch the empty ones to the working faces. As all the roadways of the mine will converge here, it is of the highest importance that this part be laid out in a convenient manner. The roadways, or "levels," enter the shaft at the bottom by means of brick arching run into the shaft walling; and as the necessity for great strength here is imperative, great caution and care will be required in designing and executing this portion of the work. The way in which the levels lead into the shaft will be understood from the drawings which illustrate the next chapter. The bottom of the shaft is laid with iron plates, called "tram plates," to facilitate the motion of the tubs; and the tramways upon which the tubs are run from the workings lead up to this plated floor. If the shaft is to be used for pumping the water from the mine, the excavation is continued down below the floor of the seam, to form a sump, over which a wooden flooring covered with tram plates is laid. When the water is to be drawn in tubs, a portion of this flooring is made removable, so that the tubs may dip during the night, or some other convenient time. When pumps are used, the suction pipe of the lower lift is dropped into this sump. As it is desirable that this sump should be capable of containing some hours' drainage, its depth should not be less than 20 feet; in some cases the depth required will be greater. With a diameter of 13 feet, and a depth of 20 feet, the sump will be capable of containing 16,587 gallons of water, a quantity considerably in excess of the daily drainage of many mines. In order to be able to store up the drainage of several days, in case of an accident to the pumps, another reservoir of large capacity is made on the course of the water flowing towards the sump; this reservoir is called a "standage." Means must, of course, be provided for placing the standage in

communication with the sump. The standage as well as the sump should be lined with brick, as prolonged contact with water promotes the disintegration and the fall of the rock.

While the sinking of the shaft and the laying out of the pit-eye are in course of execution, the surface work will be pushed on, so that the engines may be ready for winding and pumping when the opening out of the underground workings is begun.

Examples of Sinking.—In concluding the present chapter, attention is invited to the two following examples of sinking, executed as long ago as the years 1829 and 1838. These examples, which are quoted from Dunn's 'Winning and Working of Collieries,' are specially interesting, and that from several points of view. The former was the first application of metal tubbing in Scotland, and one of the earliest examples of the use of that kind of lining; and the second is conspicuous, as being the most difficult and the most costly on record. Both of these sinkings were executed according to the designs, and under the direction of experienced and skilful engineers; and they, therefore, exhibit the most approved methods of dealing with the difficulties encountered. Moreover, they are interesting and instructive, as showing how little the means employed and the methods of procedure have changed during the last fifty years:

"The Preston Grange Pit, East Lothian, remarkable as being the first example of metal tubbing in Scotland, was sunk in the year 1829. The main shaft was 10 feet in diameter; $4\frac{1}{2}$ feet being bratticed off for ventilation and the pumping apparatus; and the sinking was commanded by a pumping engine, capable of raising 400 gallons of water per minute; also with an associate winding engine. Gins, crabs, five-fold ropes, and sheaves, and other apparatus for hanging and working the pumps were duly provided.

"No sooner had the sinking arrived at the depth of 7 fathoms, than a feeder of water, of 200 gallons per minute, was met with, which required to be tubbed off, and which was accordingly done, by affixing wedging curbs, after the manner previously described, with a suitable quantity of tubbing, in segments 4 feet long by 2 feet high, and $\frac{3}{8}$ inch thick; the whole being *outset* by walling. As was expected, the water, which had forsaken the neighbouring wells, again returned to its channel, and discharged itself at the surface.

"The sinking was then resumed; and at a depth of 22 fathoms the shaft intersected the fissure of a 'trouble,' which gave out a new feeder, consisting of 300 gallons per minute. It was not till the shaft had reached the depth of 28 fathoms that a suitable water-tight stone could be selected, wherein to fix the two wedging curbs for another tub; but as there was reason to believe that this water also would rise to the surface level, it became necessary either to join it to the other tub, or to affix it, top and bottom, in water-tight stone, by means of wedging curbs, which latter mode was adopted, the shaft being first widened, to receive the tub and wedging curbs, so as to preserve an uniform finished size. The curb which surmounted the tub was held firm by a succession of wooden stays against the superior rock; after which the wedging was completed, and all this water was stopped, except a few small streamlets, which were collected into boxes and conveyed down the shaft. On account of the additional pressure, the thickness of this tub was increased to half an inch.

"The sinking was then resumed with little interruption till, at the depth of 36 fathoms, a similar feeder demanded the application of a third tub, 4 fathoms in length.

"At this period, the sinking set had been hung upon ground ropes; but a thin seam of coal caused it to be converted into a standing set, 31 fathoms long, which was done by excavating a space

for the reception of a cistern, fixed upon strong buntons across the shaft. At the same time the hitherto common pump was replaced by a forcing set, with ram; the barrel being bestrode by a pair of iron rods, for the working of the intended hanging pumps underneath the forcing barrel.

"The second column of pumps now became the hanging set, and the sinking proceeded to the depth of 44 fathoms, where $4\frac{1}{2}$ fathoms of tubbing were again required, to stop back water to the extent of 350 gallons per minute. These segments were increased in thickness to five-eighths and six-eighths, with still deeper flanges.

"Here a new difficulty occurred from a considerable discharge of carbonic acid gas with the water, which affected the eyesight of the sinkers; and it so operated against the tightening of the tub, that at one time it was feared that air-pipes to the surface would have been necessary to discharge the gas.

"As all the waters were derived from an origin considerably above the level of the shaft top, the pressure upon the last-mentioned tub, at 264 feet perpendicular, exceeded 120 lb. upon every square inch of its surface; and as the surface contained an area of 768 square feet, it sustained a pressure of 6000 tons.

"Little additional water was met with below this point; but at the depth of 55 fathoms the second column of pumps was converted into a fixed set, by establishing another cistern, and the third column was attached in its turn, as the sinking set. At the end of two years the coal was sunk through 70 fathoms in depth, at which period the total water did not exceed 50 gallons per minute, or one-eighth part of the engine power.

TABLE OF THE DIFFERENT TUBS AND THEIR EFFECTS.

	Weight per Segment.	Weight per Fathom.	Length.	Quantity of Water per Minute stopped.	Depth of Bottom of Tub from Surface.
	cwt. qr. lb.	cwt.	fathoms.	gal.	fathoms.
1st Tub	2 0 0	48	8	200	9
2nd "	2 2 0	60	$6\frac{1}{2}$	300	28
3rd "	2 3 0	66	4	300	36
4th "	3 2 0	80	$4\frac{1}{2}$	350	44
			23	1150	

The Dawdon Winning, in the Hetton district of the county of Durham, remarkable as being the most arduous and costly on record, was commenced in the year 1838.

"The South Hetton Company, having considerably increased their tract of coal under lease, decided on the propriety of also increasing their powers of working. A site for a new winning was fixed upon, and the necessary borings commenced, to ascertain the thickness of the sand underlying the magnesian limestone. This having been accomplished, the ground was broken for the first shaft on the 19th February, 1838. Two months afterwards another shaft was begun, and they were carried forward simultaneously, both pits being 14 feet in diameter.

"The upper stratification consisted of:

	fa.	ft.	in.
Soil, gravel, and strong blue clay	7	4	9
Soft marl, mixed with beds of craggy limestone	48	4	9
Strong brown limestone	19	0	0
Blue metal, soft	0	2	6
Quicksand	5	4	6
Total	81	4	6

"Little or no water was met with till the pits reached the depth of 32 fathoms, after which the quantity gradually increased until the sand-feeders were encountered, which were successively tubbed off whenever favourable foundations were met with; so that, previous to the sand being tapped, the shafts were freed from water. On the 26th June, 1839, the sand-feeders burst away from the bottom of the shaft, throwing up, with gigantic force, 4 feet of strong limestone which intervened between the bottom of the shaft and the top of the sand. With such violence did this eruption take place, that before the capstans could heave the pumps up from the bottom they were all choked, and upwards of 10 feet of sand deposited in the pit.

"The difficulties of this gigantic and critical undertaking now commenced in earnest. The engine power placed on the shaft which first pierced the sand not being able to make any impression upon the water, several large bore-holes were made through the bottom of the other shaft, then close upon the sand, so that the united engine power might be applied. This being accomplished, every nerve was strained to make the application most effective: 4678 gallons per minute were drawn to bank for some time, without making any sensible impression upon the feeders, and which thus effectually prevented the further progress of sinking.

"This difficult and unpromising state of things would have allayed the ardour of less adventurous speculators; but the company were determined, cost what it might, to brave every obstacle, notwithstanding the warnings and condolence of many sage persons in the trade.

"A third shaft, of greater diameter than any hitherto sunk, was commenced and furnished with an unprecedented force of engine power, as applied to one shaft. This new pit was urged forward with every despatch, and in six months reached the depth of 73 fathoms, being completed with walling, metal tubbing, brattice, pumps, cisterns, &c. Two pumping engines and two winding engines, constructed also to pump, were likewise erected upon this shaft, and were set to work simultaneously with the sinking. The total amount of engine power thus brought into action was as follows, viz.:

	Horse-Power.
3 Pumping engines of 350 horse-power each	1050
2 Winding engines, also employed in pumping, of 130 each	260
1 " " " "	100
2 " for drawing stones, of 25 each	50
1 " " "	18
Total horse-power	1478

"To maintain this enormous engine power thirty-four boilers were required, and also twenty-seven columns of pumps, viz. eighteen columns of $19\frac{1}{2}$ inches, and nine of 16 inches diameter.

"When the necessary preparations were completed, the sand was broached in the last-mentioned pit, and the operation of sinking the whole of the shafts through it was commenced. The sand, although tolerably firm when dry, was found to be so disintegrated by the action of the water, that it was necessary to suspend the men whilst working in it. The scouring effect of this mixture of sand and water upon the buckets of the pumps as well as upon the working barrels, was found to be a serious impediment to the progress of the work, the buckets being frequently 'worn off' at the end of from two to four hours. The engines at this time drew 10,000 gallons per minute. Every expedient which the ingenuity of the persons in charge of this difficult work could devise was put in requisition. Success at length crowned their exertions, by the completion of all the shafts through this formidable quicksand.

"The whole of the feeders of water were effectually stopped back by metal tubbing, of from $\frac{3}{4}$ inch to $1\frac{1}{4}$ inch in thickness, and the shafts rendered perfectly dry.

"The two original pits were then sunk to the several seams of coal usually found in the district, and which in this locality consist of twenty-three beds, five of which are found to be of workable thickness.

"The Hutton seam, lying at the depth of 248 fathoms from the surface, was sunk to on the 15th April, 1843.

"The thicknesses of the three principal seams of coal recognized in the Wear district were found here as follows, viz.:

	ft.	in.
The Main Coal	6	2
The Low Main Coal	4	7
The Hutton Seam	5	0"

CHAPTER V.

DRIVING OF LEVELS, OR NARROW WORK.

When the shaft has been sunk to the coal, and completed for all the purposes which it is intended to serve, there remains much important work to be done before coal can be extracted. To proceed at once to the excavation of the mineral would be to endanger the safety of the shaft, and to create serious obstacles to the subsequent working of the seam and the efficient ventilation of the working places. The extent to which the preliminary operations of opening out a mine should go will be determined by local conditions, and more especially by the amount of capital to be expended and the limit of time allowed by commercial and other considerations. But whatever these considerations may be, a certain amount of preparatory work must necessarily be performed in laying out the workings in a manner suitable to the nature of the subsequent operations of extracting the coal. And it should be borne in mind that the more systematically and completely this preliminary opening up of the ground is performed, the more economically and safely may the extraction of the coal be effected. It is an altogether false economy that leads to a curtailing of the time and expense requisite to the opening out of a new colliery, or portion of a colliery, since the consequent difficulties, which can never be removed subsequently, or even modified in an important degree, far more than compensate the first expenditure of money, or the inconsiderable gain of time.

As the work incident to the opening out of a mine is not immediately remunerative, it is generally described as "dead" work, or frequently, on account of the narrow width of the working face, as compared with the ordinary working places, as "narrow" work. The excavations which constitute the dead or narrow work consist of drifts, headings or roadways, called "rolley-ways," "way-gates," "gate-roads," "water-gates," and "levels," driven out from the mass of coal left to support the sides of the shaft and called, on that account, "shaft pillars." These levels are the principal roadways, airways, and waterways of the mine; through them all the produce of the mine will have to be conveyed, and the whole of the air which is to ventilate the workings, as well as the water flowing therefrom, will have to pass. It is therefore obvious that these excavations are of essential importance in the economy of a mine, and that their design, execution, and maintenance demand the most careful consideration and attention. The mode of laying out these pioneer excavations will be in the main the same, whatever the system of working adopted may be. But modification may be required to conform to the exigencies of the case, due to the angle of dip, the existence of faults, or any other of the numerous circumstances that may accompany the occurrence of a seam. In the example which we shall assume for purposes of illustration, the seam will be supposed to dip at a small angle, and to be free from disturbing circumstances, in order to form a typical case, that shall involve a syste in its entirety.

Shaft Pillars.—A large mass of coal must be left unwrought around the shaft, as a support, which mass will be cut through only by the narrow excavations that constitute the roadways to the shaft. These drifts divide the mass into detached blocks, which are called the shaft pillars. It is hardly necessary to remark that these pillars are of essential importance, since they support the shaft which forms the highway between the mine and the surface. It is easy to see that the slightest movement in that portion of the beds through which the shaft passes must necessarily be destructive to the latter; and hence it becomes essential to the very existence of the mine to provide sufficient means for preventing such a movement from taking place. In view of the inevitable destruction which must result to the shaft from the yielding of the shaft pillars, it is surprising that in some instances these have been laid out with dimensions utterly incapable of resisting the forces brought to bear upon them, and that frequently their dimensions are reduced, for economical considerations, to a limit which leaves no margin for safety.

The dimensions of the shaft pillars are determined by four conditions, namely, the depth of the seam from surface; the angle of inclination of the beds; the strength of the coal; and the nature of the thill or floor. In no case can safety be obtained with pillars less than 35 yards square; these may, therefore, be considered as the minimum dimensions in the shallowest mines, when the other conditions are favourable, say up to a depth of 150 yards. Beyond this depth the dimensions may be increased by 5 yards for every 25 yards of increase; that is, the pillars of a shaft 175 yards deep will be 40 yards square; those of a shaft 200 yards deep, 45 yards, and so on. These dimensions are given as sufficient, on the assumption that the other conditions are favourable. But it is evident that those conditions may be such as to require an augmentation of the dimensions, as determined according to the depth alone. Thus, if the strata are highly inclined, the tendency of the pillars to yield is greater than when the strata are flat. The difficulty of preserving the shaft through steep measures is, in Belgium, often found to be a serious one. The strength of the coal will also materially affect the resistance of the pillars to compression. The difference in the strength of coal, as pointed out in a previous chapter, is very considerable, and this difference must be taken into account in determining the dimensions of the pillars. But perhaps the most important of these determining conditions is the nature of the thill or floor of the coal seam. When this floor consists of soft underclay, the pressure of the pillar upon it tends to force it to rise in the roadways between the pillars. This tendency of the floor to rise between the pillars is often very observable in the workings, when it is known as the "creep." Of course, the displacement of the floor in this way causes the pillars to sink; and the downward movement of the superincumbent beds is accelerated by the crushing effects which take place in the pillars, by reason of the unequal strain thrown upon them. The only way of counteracting this tendency is by increasing the dimensions of the pillars, so as to distribute the pressure over a wider area. The amount of increase demanded by each of these conditions cannot be stated in a general manner. It is a question that will have to be determined for every individual case, in accordance with the circumstances by which it is surrounded, and the degree in which the conditions are modified. The proper method of procedure, in dealing with this question, is to determine the dimensions required by the depth alone, and then to augment these, if necessary, for each of the other conditions, in a proportion adequate to its requirements. The experience of the district will in this matter be of great avail.

The Levels.—When the dimensions of the shaft pillar have been determined, the levels may be set out, the designing and driving of which constitute the work of opening out the mine. The

direction of these levels is determined by that of the dip of the strata, and, as remarked in the preceding chapter, the relative positions of the downcast and upcast shafts will be dependent upon the same conditions. As the levels are to be driven in the seam of coal, it is evident that the horizontality of their floor, whence their designation of level is derived, can be obtained only by driving them in the direction of the *strike* of the beds, which, as already pointed out, is at right angles to their dip. In this direction, therefore, which is known among miners as the water-level direction, is that of the levels to be driven out from the shaft. Those so-called levels are, however, not perfectly horizontal, for reasons that will hereafter appear, but their deviation from the horizontal is made as little as the conditions will admit, and in no case is it more than trifling in amount. A consideration of the conditions which determine the position and the direction of the levels will show that these must greatly influence the choice of the position of the shafts. The relation of the levels to the shafts and to the coal to be wrought, in position and in direction, will be understood by a reference to the plan shown in Fig. 446. This plan represents typically the method of laying out the workings generally followed in England.

The direction of the dip of the seam is shown in the plan by the arrow upon the coal to be wrought C C. The downcast shaft is shown at D, and directly to the rise of the downcast, and distant 15 yards, is the upcast shaft U. When these shafts have been carried down to the requisite depth, the first step in opening out the workings is to connect them by a headway or drift driven through the coal. This connection will provide for the ventilation by enabling each shaft to serve the purpose for which it was ultimately intended. For the current of air, instead of passing down and up each shaft on opposite sides of the brattice, will now descend through the downcast D, and ascend through the upcast U. It now remains to set off the levels perpendicularly to the direction of the dip of the seam, as shown at *a b*, *a c*, *d e*, *d f*. These are driven out from the shafts in opposite directions, and as they will be in all respects identical on each side of the shafts, it will be sufficient to describe those on one side only. Before describing these levels, however, it should be observed that in extensive collieries a third level is usually added, mainly to ensure a more efficient ventilation; and also that the shafts may be situate farther apart than in the example chosen for illustration. Under such conditions, the shaft pillars will be laid out, and the levels driven out from them somewhat after the manner represented in Fig. 447, in which plan the levels *a* and *b* correspond to the levels *a b*, *d e*, in Fig. 446.

In driving the levels out from the shafts, care must be taken, as before remarked, not to weaken the ground in that part. This condition will generally necessitate a walling to sustain the sides and the roof of the level, timbering being insufficient in all but exceptional circumstances. Whenever timbering is used to support the roof in such situations, it will be well to wall the sides. But an arching of brick is far preferable; and if the floor is of a weak character, the walling should rest upon an invert.

Of the levels *a b* and *d e*, the former or lower is the drain, water-level or water-gate, one of its uses being to convey the water, which gravitates towards it from the workings situate above, to the pumping shaft. The upper level *d e* is the main road, rolley-way, or way-gate, through which the mineral will be conveyed to the shaft. As these are the main outlets to the mine, and as, moreover, they constitute the air-channels through which the workings will be ventilated, it is obvious that their design and construction demand careful attention to render them convenient and durable. The facilities which these roads afford for the easy and rapid transport of the coal from the working faces

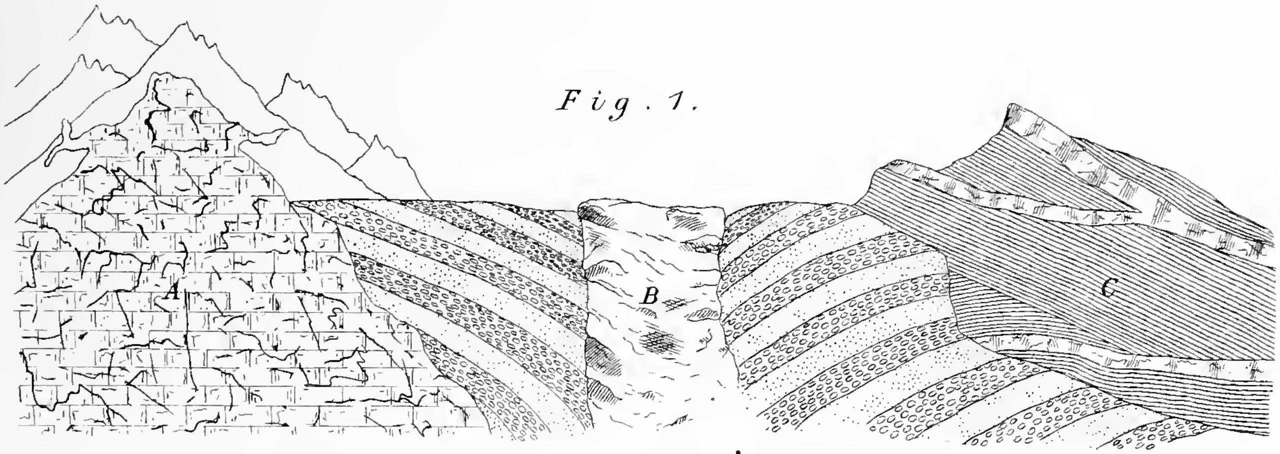
to the shaft will very materially influence the quantity of the output and the cost of delivery at surface, or "bank," as the surface around the mouth of the shaft is technically called. And the consequences of an accident resulting in the blocking up of these roads are of too serious a character to leave any precaution unnecessary.

Form, Dimensions, and Inclination of the Levels.—The section of a level, unlike that of the shaft, offers but little variation in form. When timbered the sides are generally vertical, and the top or roof horizontal, the section in such a case being rectangular. The sides may, however, incline towards each other, thus giving a greater width at the floor than at the roof. When walled, the sides are vertical, and the roof is arched.

The dimensions will be determined by three conditions: the thickness of the seam through which the levels are driven, the strength of the roof, and the requirements of the means of transport. If the seam be of moderate thickness, say from 6 to 8 feet, the level will be driven between the roof and the floor; that is, the whole of the seam will be removed, and the height of the level will be equal to the thickness of the seam. When the thickness exceeds 8 feet, the level is driven from the floor to a height of 7 feet or 7 feet 6 inches, and the remainder is left to form the roof. When, on the contrary, the seam is too thin to afford a convenient height for a horse-road, either a portion of the roof must be stripped down, or a portion of the floor removed to give the necessary height; and as such labour is altogether unproductive, the minimum height demanded by convenience will not be exceeded. Under some conditions this may be as little as 5 feet. The width of the excavation will be determined according to the strength of the roof, and the requirements of the means of transport. If the roof be of a very weak character, it may be necessary, to insure safety, to limit the width to 5 feet. If, on the contrary, the roof be very strong, this width may be increased to 10 feet. Thus the limits of height and width of a level may be stated as 5 feet and 8 feet, and 5 feet and 10 feet respectively. The width necessary to convenience of transport will be determined by the extent of the workings, and the degree of activity to be developed in them. In most cases, the rolley-ways will have to be laid out to a width sufficient for a double line of tram rails, so that a train of empty tubs may be returning to the workings while a train of loaded tubs is running out towards the shaft. In general, the width which best fulfils all the requirements of the case is from 7 feet to 8 feet, when the strength of the roof is sufficient. An important use of the levels, to be borne in mind when determining these dimensions, is that of conveying air to and from the workings. The large quantity required necessitates a large sectional area in the ways, and on this ground, as will more clearly appear when we treat the subject of ventilation, ample width is desirable. For economical reasons, the sectional area of a level is frequently reduced to its lowest practicable limits; but to assume that the cost of driving a level diminishes as its sectional area is an error. When the miner is compelled to work in a space insufficient to allow freedom in his movements, there is a very notable loss of useful effect due to the restriction, which loss, by prolonging the labour, increases the cost of the work. Also the labour of driving a heading of small sectional area is relatively greater than that required by a heading of larger dimensions, since the amount of side cutting is proportionally greater in the smaller section. Besides this, the coal extracted from the smaller face is more broken, and consequently less valuable, than that hewn from the larger face. The only advantage offered by the smaller section lies in the diminished labour of conveying away the dislodged mineral.

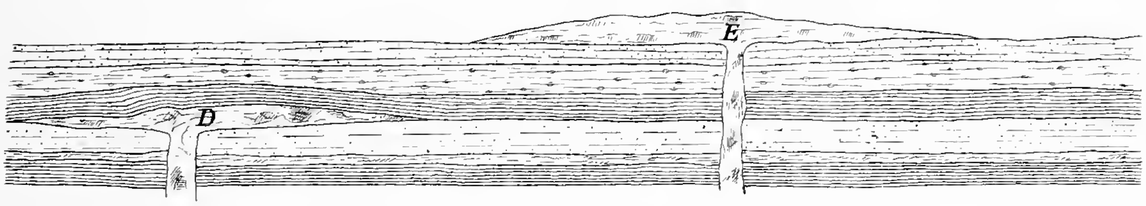
It has already been remarked that the levels are not driven truly horizontally. There are two important circumstances which require them to have a slight inclination towards the shaft. The

Fig. 1.



Eruptive, Disruptive and Intrusive Igneous Rocks.

Fig. 2.



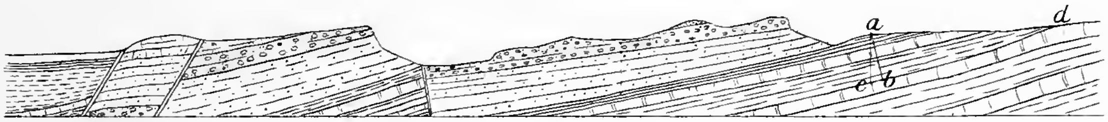
Interbedded and Overlying Igneous Rocks.

Fig. 3.

Thinning out of Rock Beds.

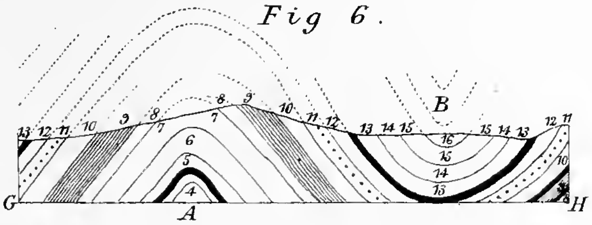
E & F N. Spon London & New York

Fig 4.



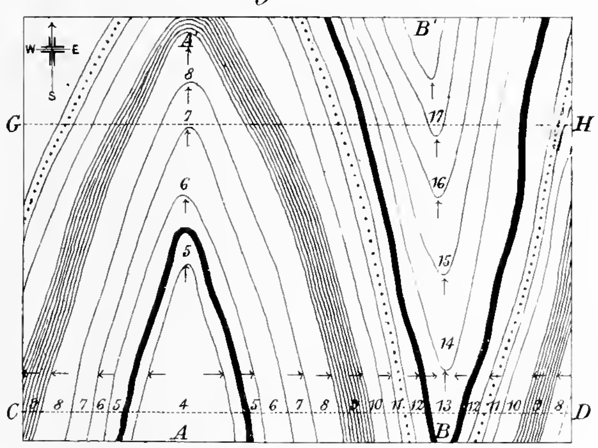
Inclination of Rock Beds. Market Drayton, Salop.

Fig 6.



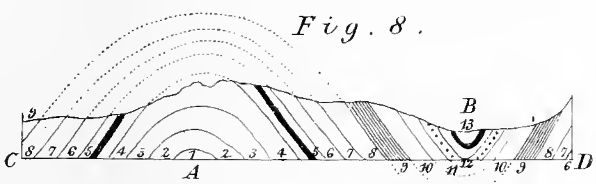
Anticlinal and Synclinal Curves _ Section through G.H.

Fig. 7



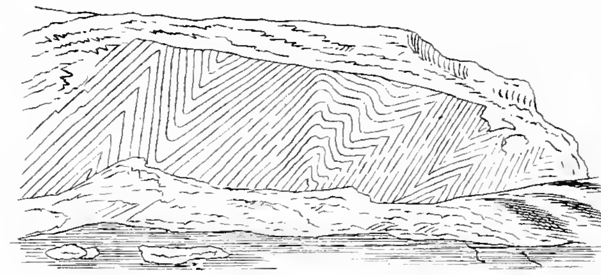
Anticlinal and Synclinal Curves _ Plan.

Fig. 8.



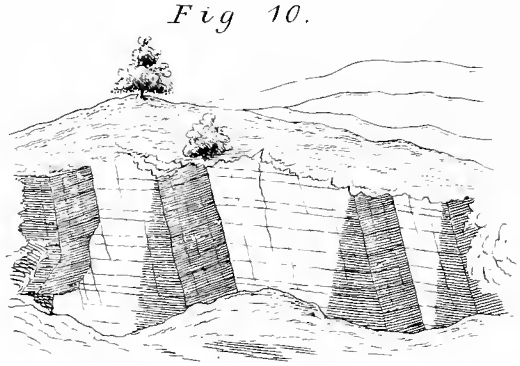
Anticlinal and Synclinal Curves _ Section through C.D.

Fig. 5.



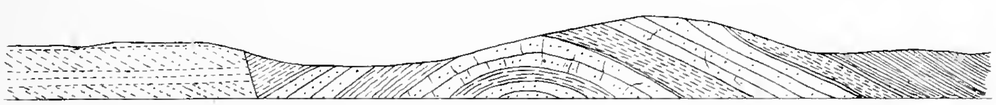
Contortions _ Loughshinny Co. Dublin.

Fig 10.



Rock Joints. _ Mallow, Co. Cork.

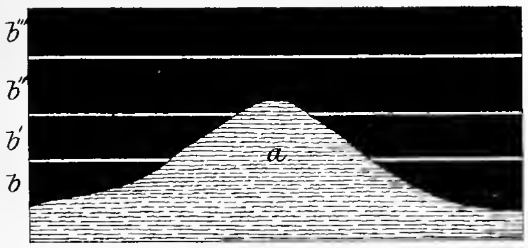
Fig. 9



Anticlinal. _ Frodsham, Cheshire.

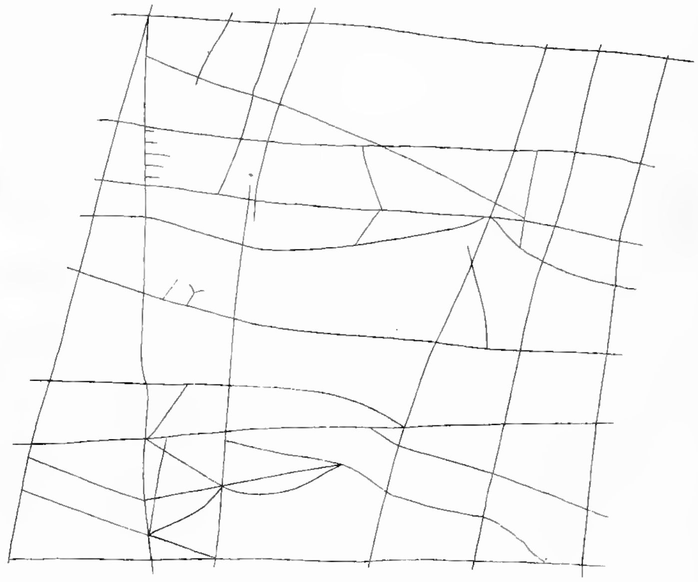
E & F.N. Spon. London & New York

Fig 12.



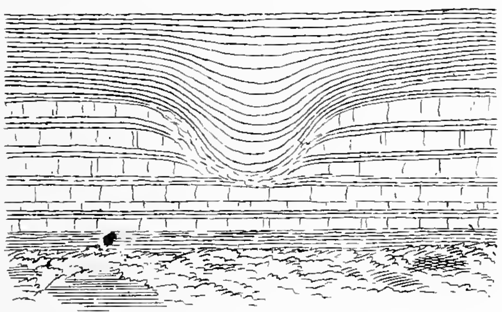
Swell or Horse's Back.

Fig 11



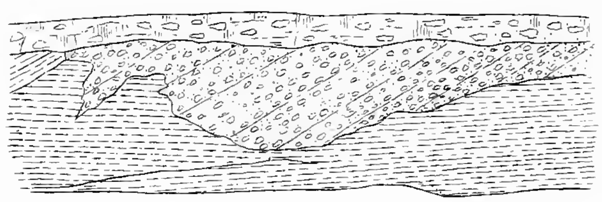
Plan of Joints in Rock _ Burren, Co. Clare.

Fig. 13.



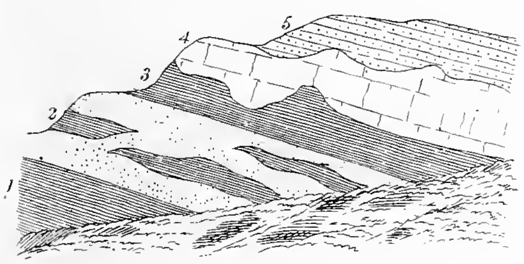
Trough near Paris.

Fig 14.



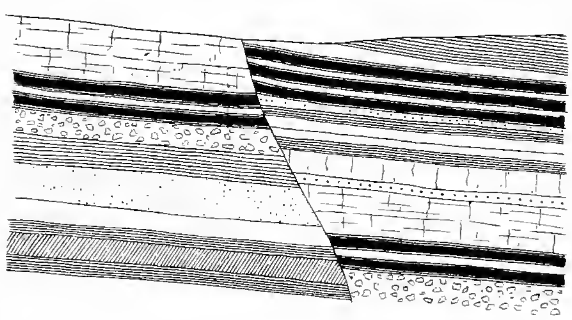
Fault of Erosion _ Stourton. Staffordshire.

Fig 15



Fault of Erosion.

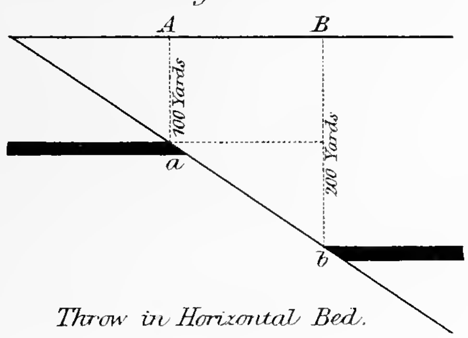
Fig. 16



Fault of Dislocation.

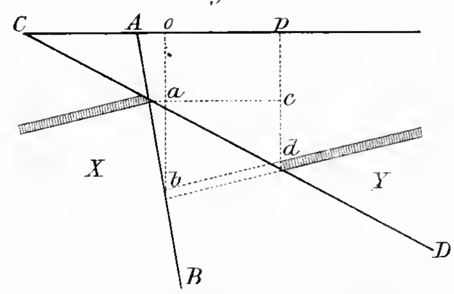
E & F.N. Spon London & New York.

Fig 17



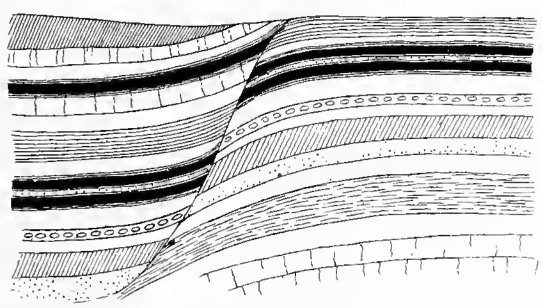
Throw in Horizontal Bed.

Fig 18.



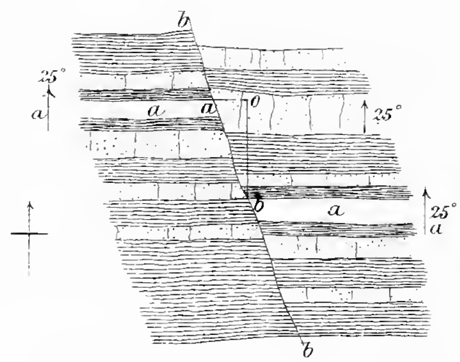
Throw in Inclined Bed.

Fig 19



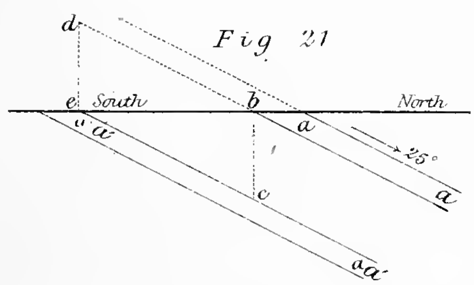
Distorted Fault

Fig 20



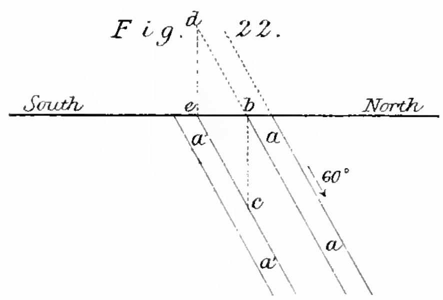
Apparent Lateral Shift _ Plan.

Fig 21



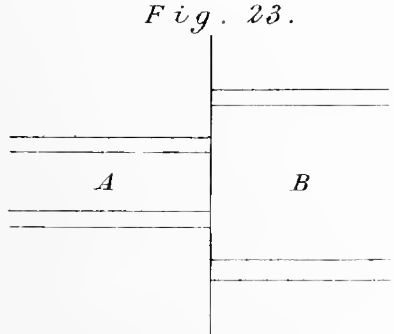
Lateral Shift _ Section.

Fig 22.



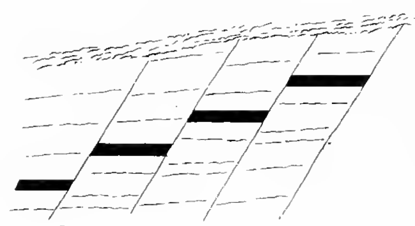
Lateral Shift _ Section.

Fig. 23.



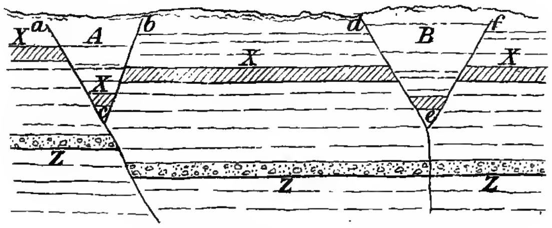
Lateral Shift _ Plan.

Fig 24



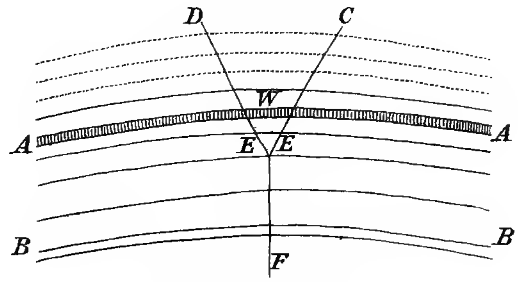
Step Fault.

Fig. 25.



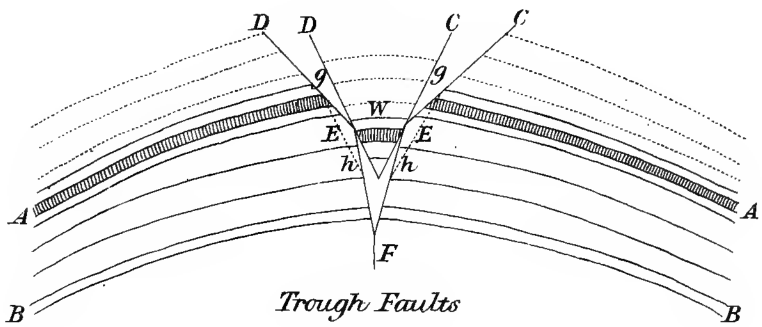
Trough Faults

Fig. 26.



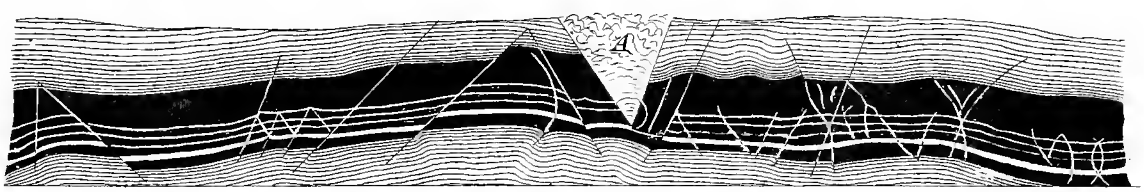
Trough Faults.

Fig. 27.



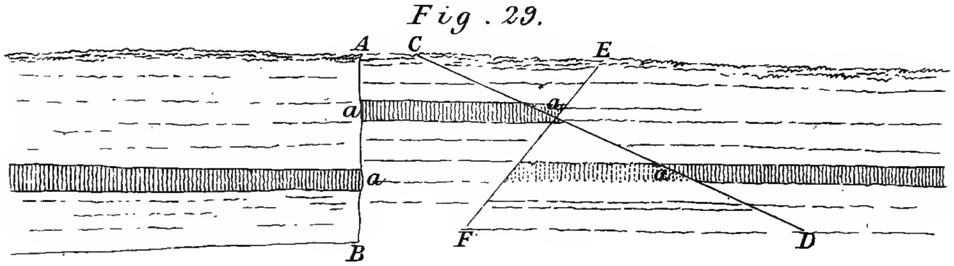
Trough Faults

Fig 28



Trough Fault in Staffordshire Thick Coal.

Fig. 29.



Direction of Throw.

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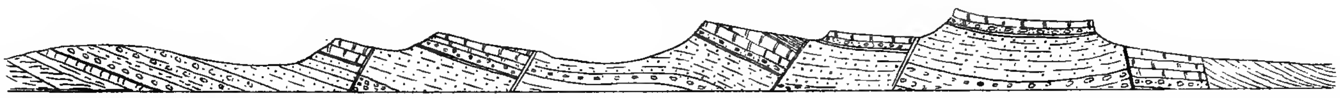
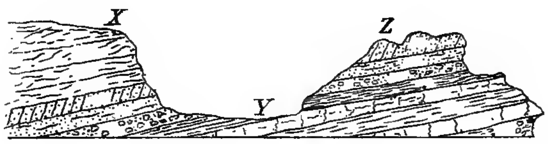
Fig. 30.



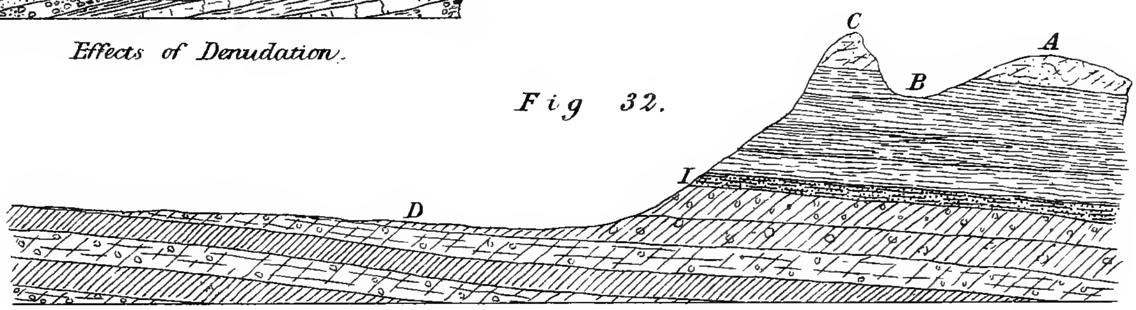
Faults of Dislocation _ Peckforton Hills, Cheshire.

Fig. 31.



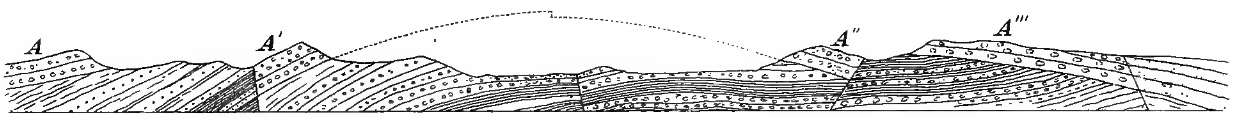
Effects of Denudation.

Fig 32.



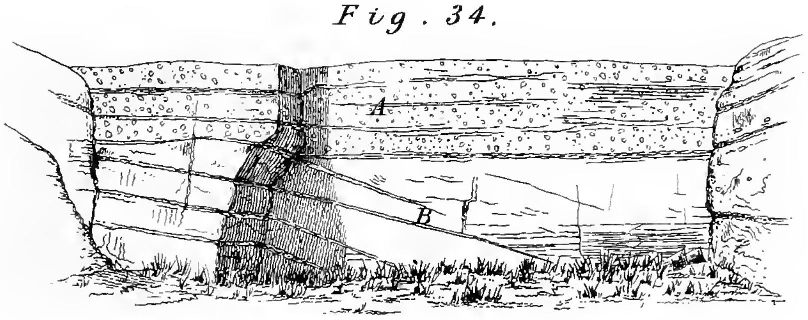
Effects of Denudation._ Newton, Yorkshire.

Fig 33.



Effects of Faults and Denudation _ Trentham Park, Staffordshire.

Fig. 34.



Unconformability. __ Cheswardine, Salop.

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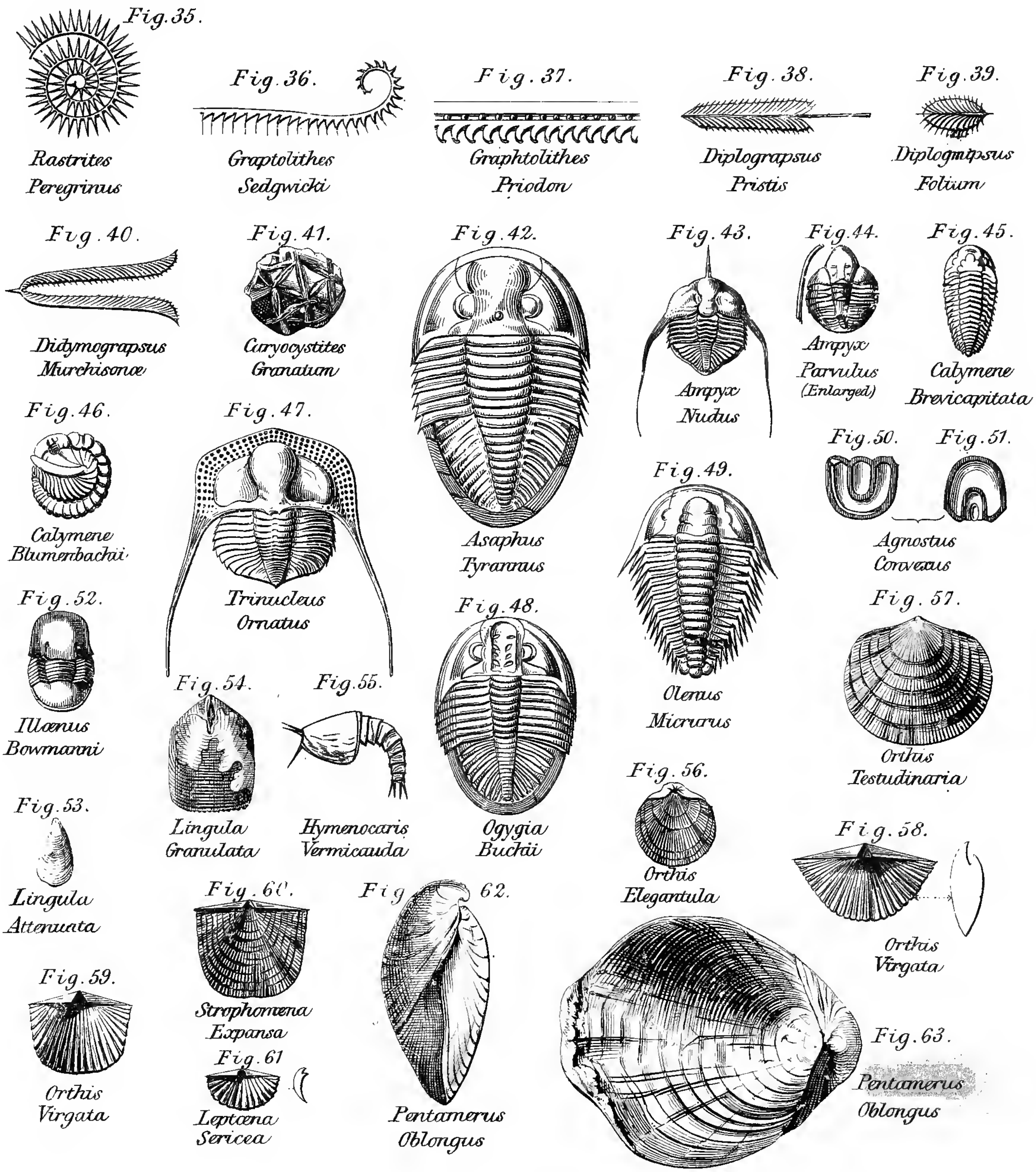
CHARACTERISTIC FOSSILS OF THE SILURIAN PERIOD.



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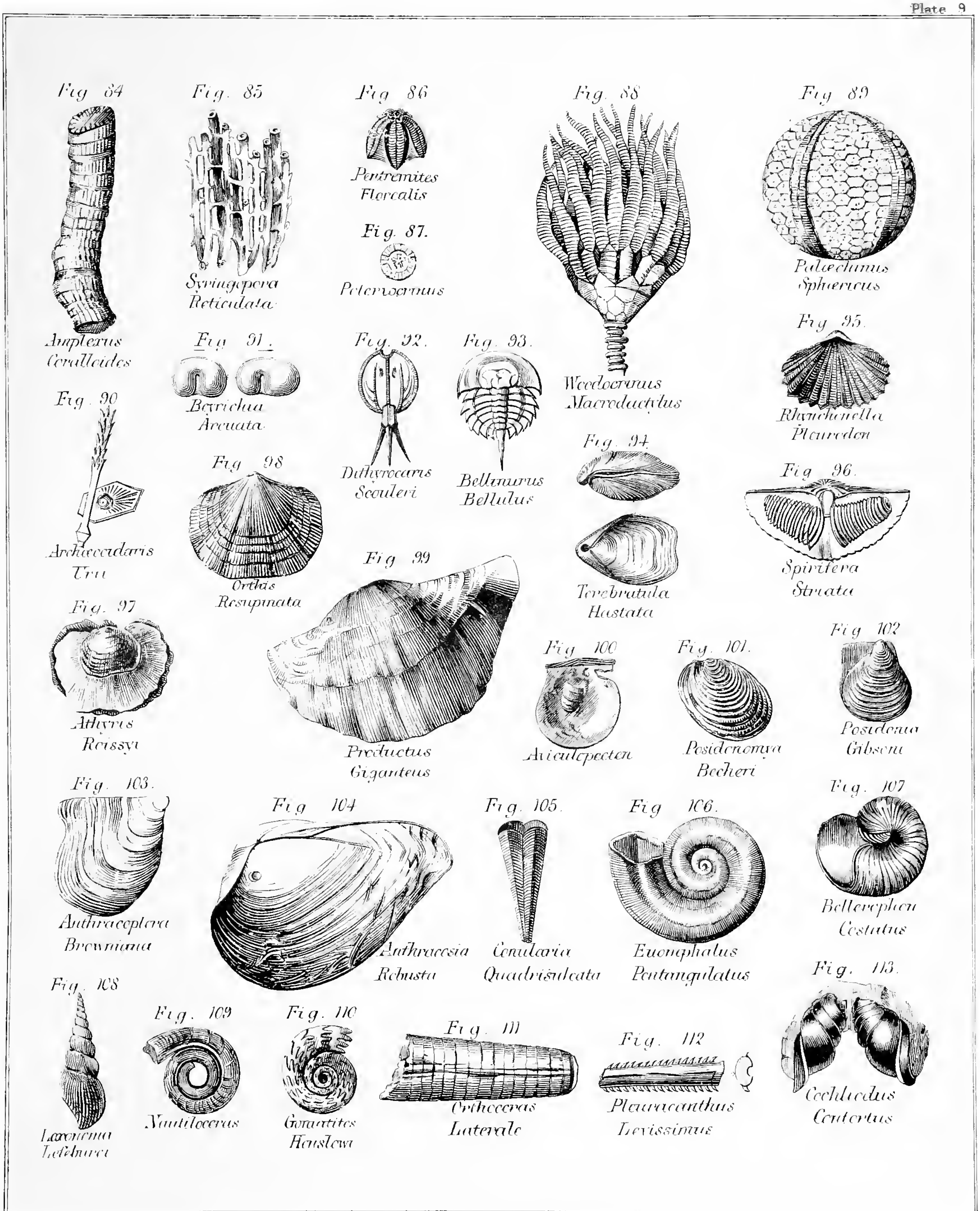

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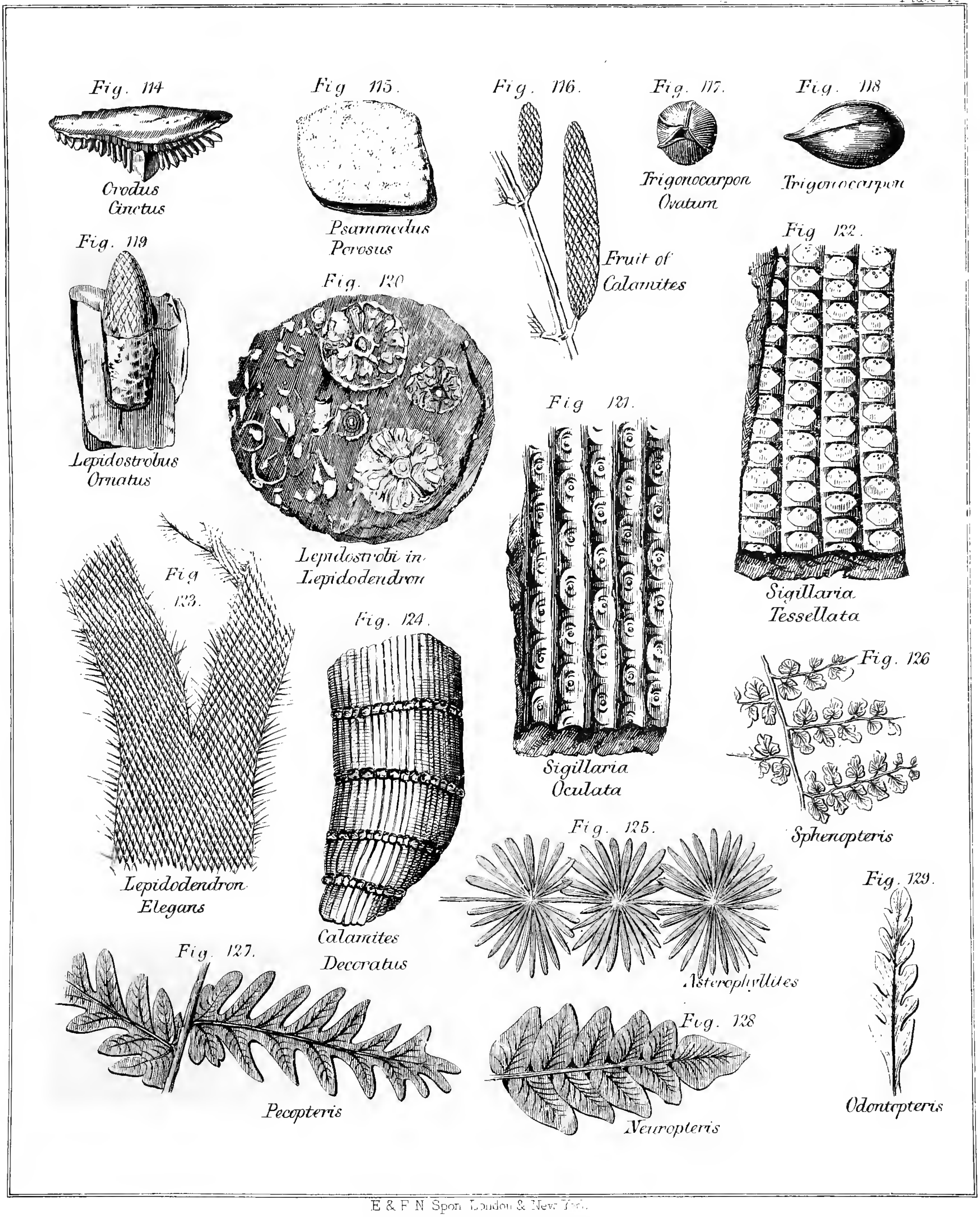
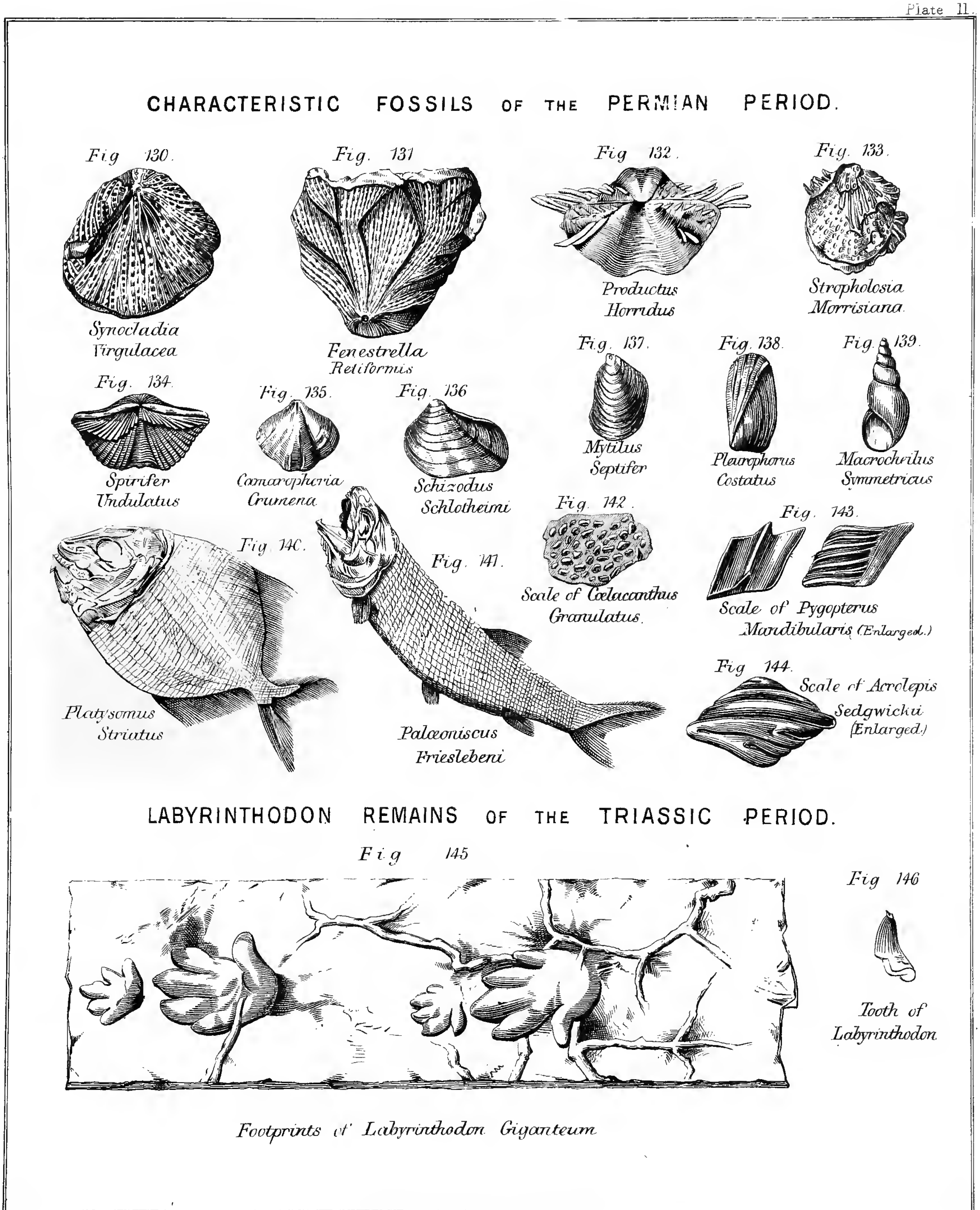


E & F N Spon London & New York.



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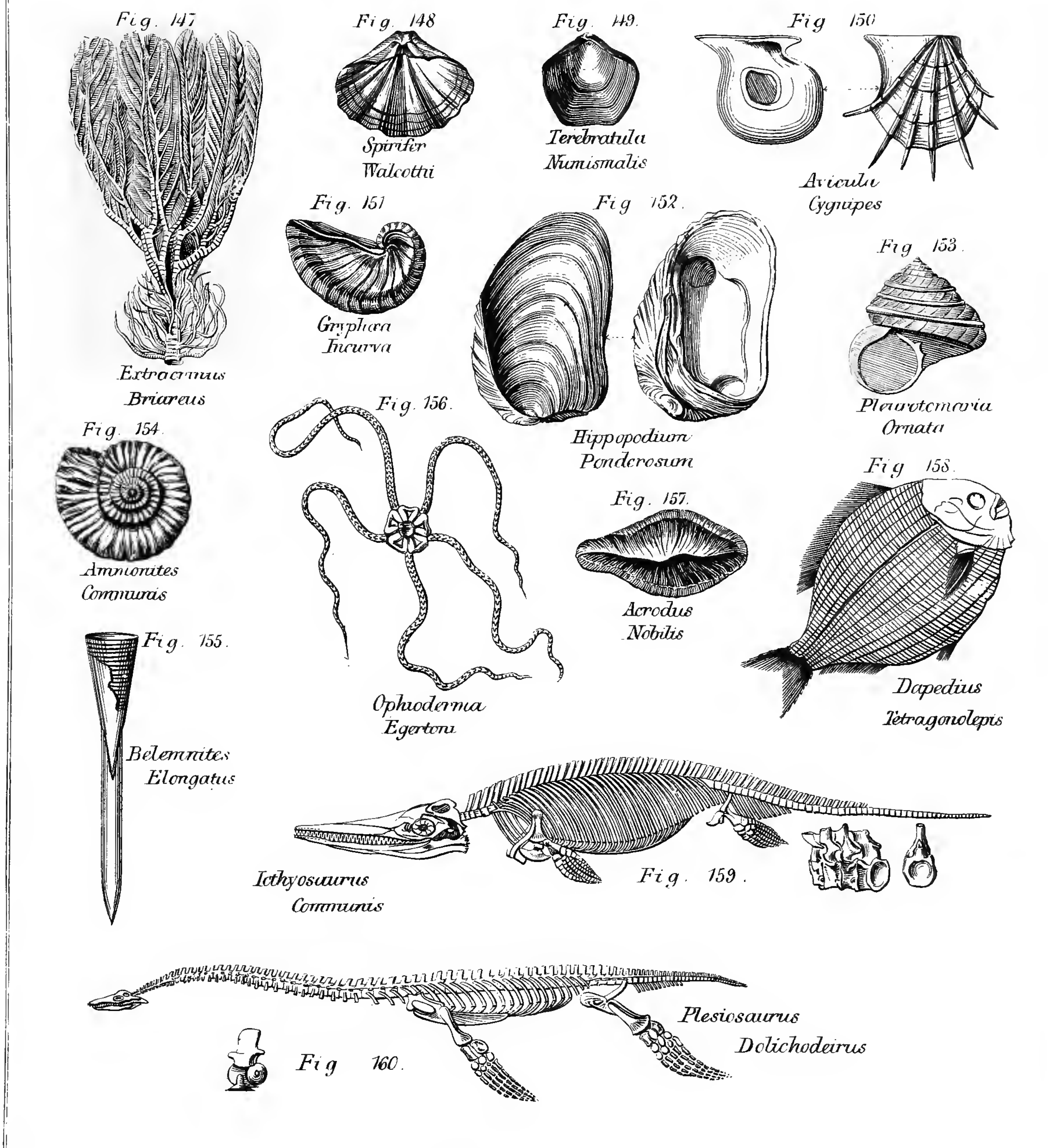
CHARACTERISTIC FOSSILS OF THE LIAS.



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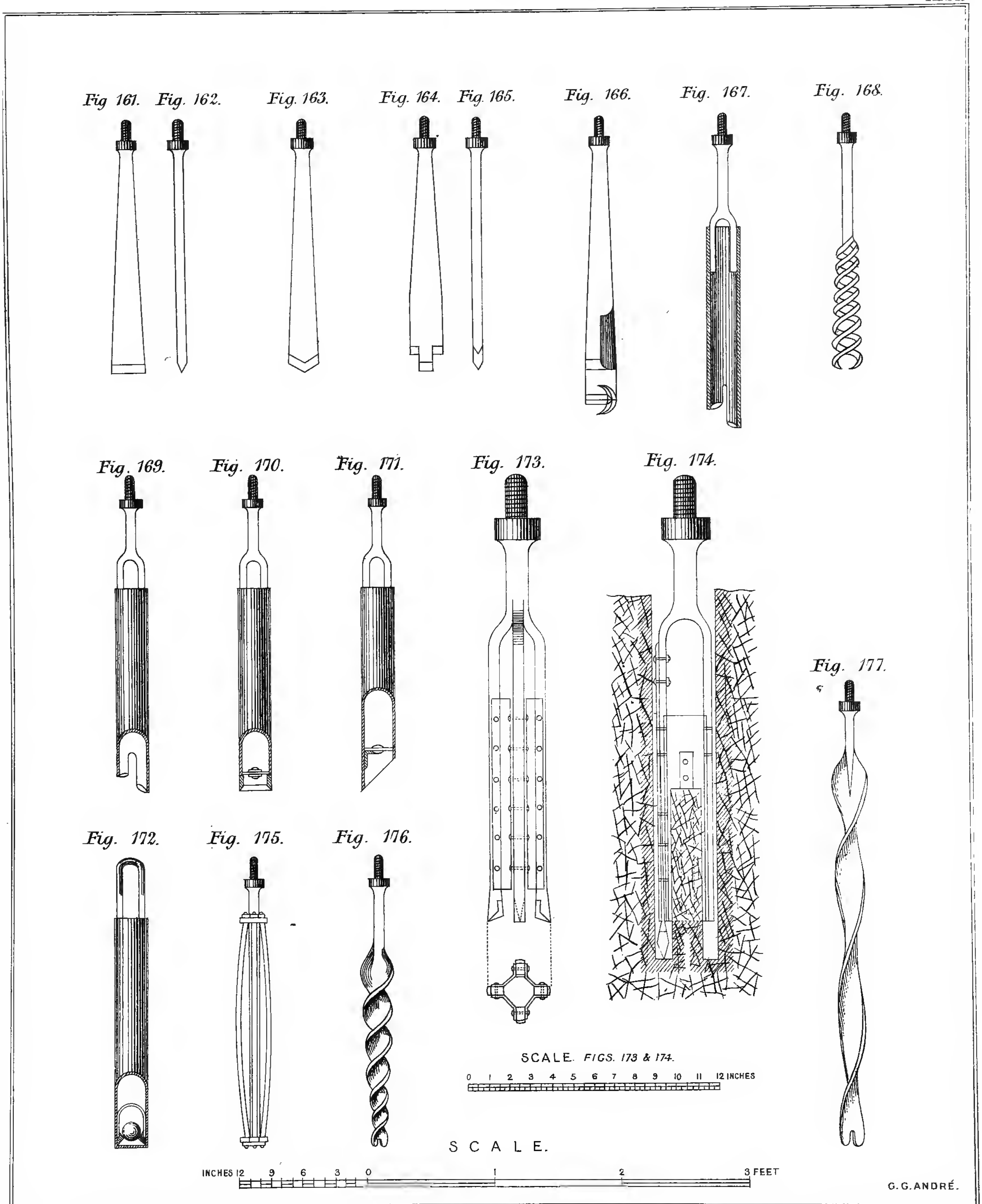

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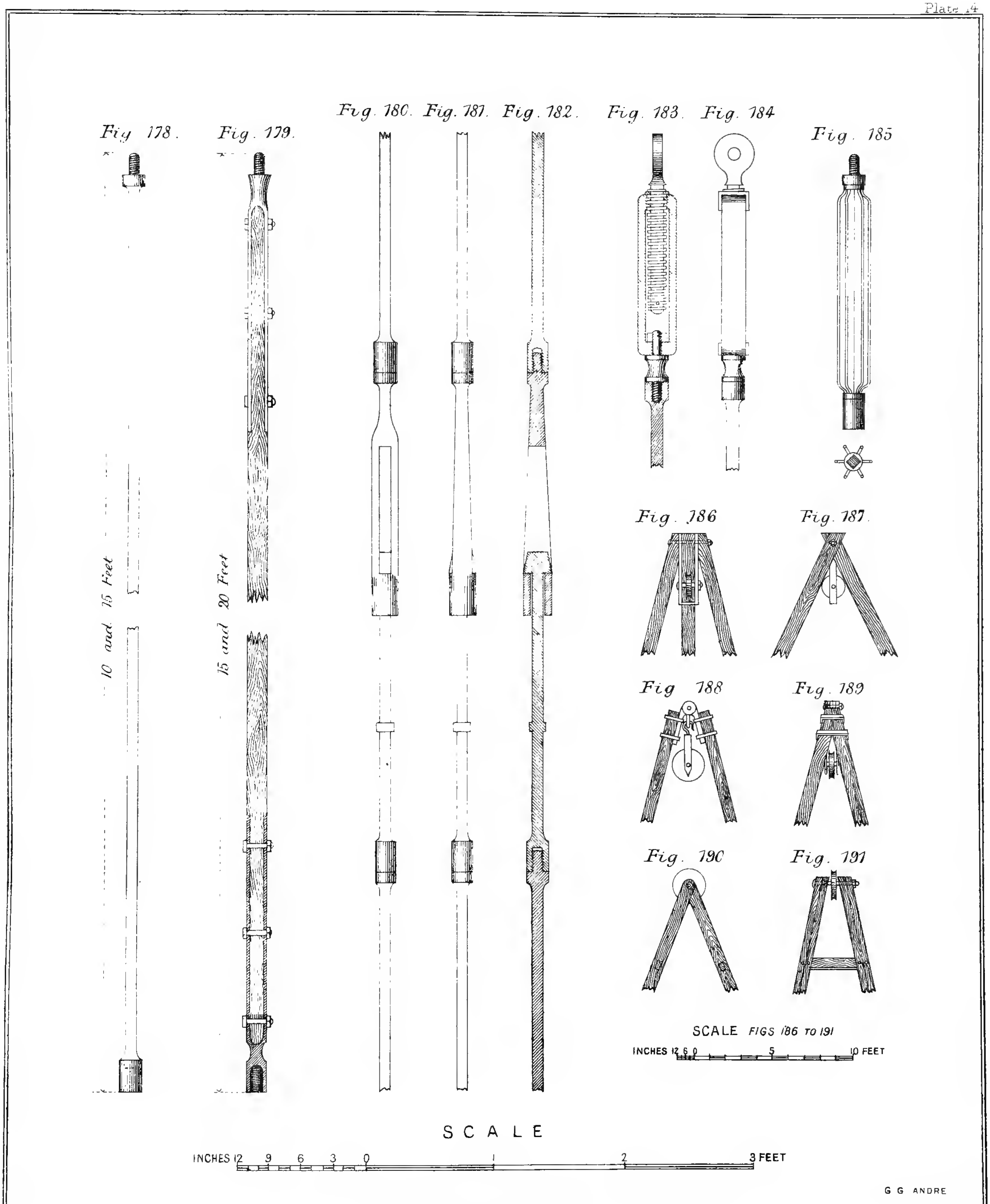

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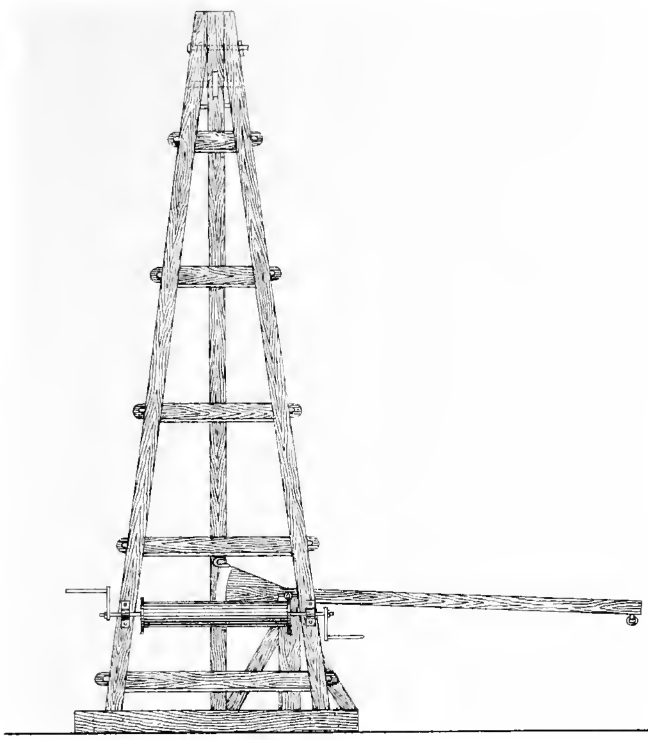
Fig 192



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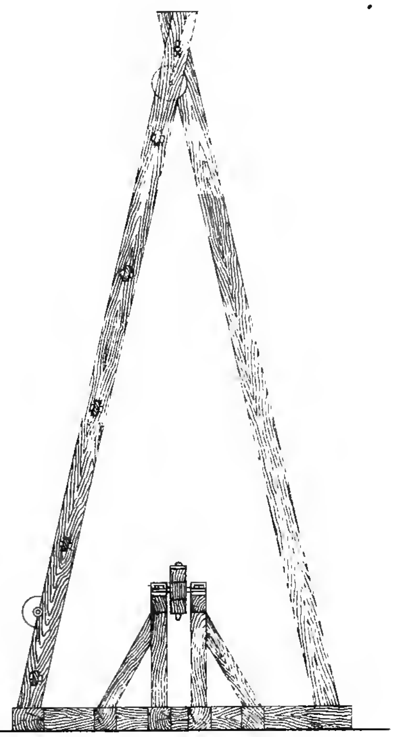

Fig 201

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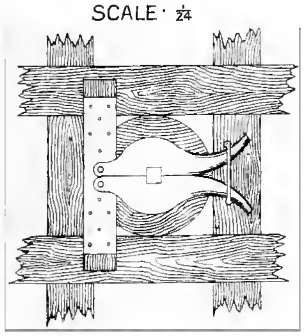

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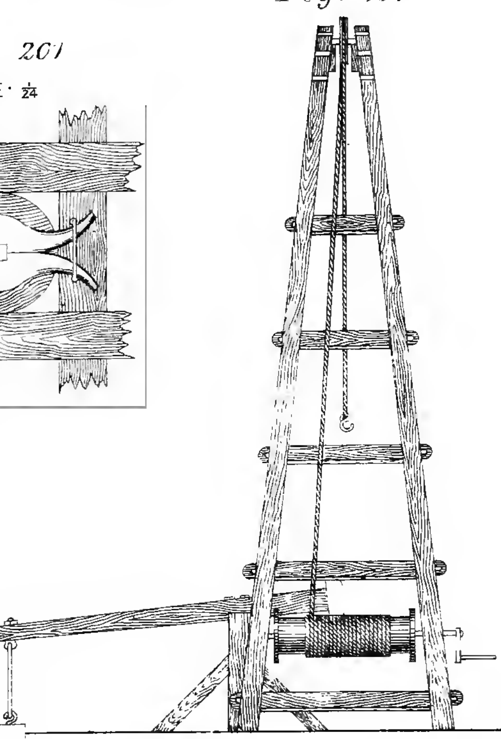

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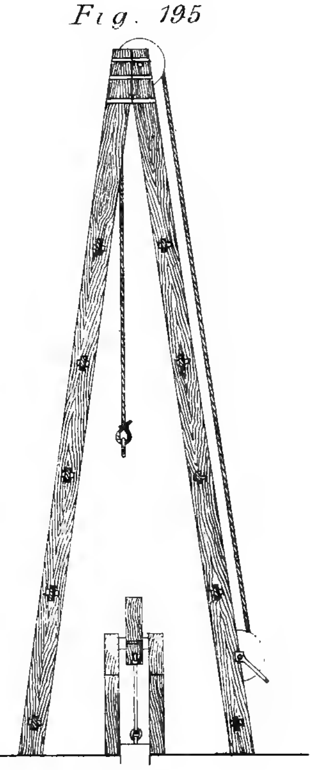

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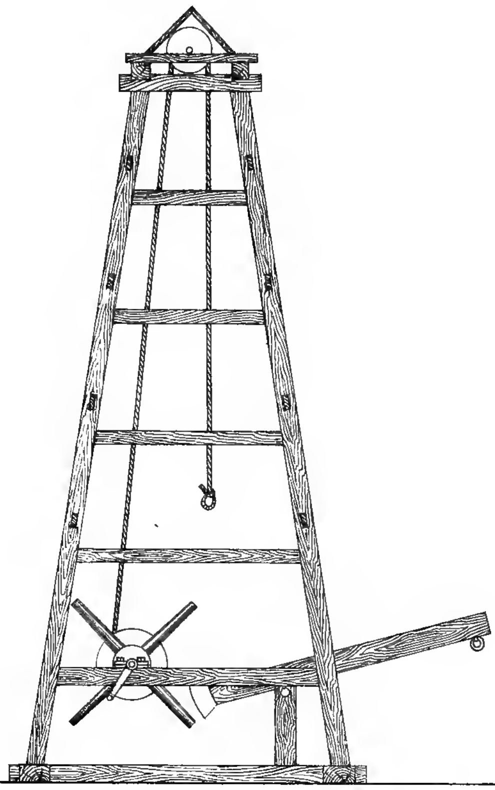
Fig 196.



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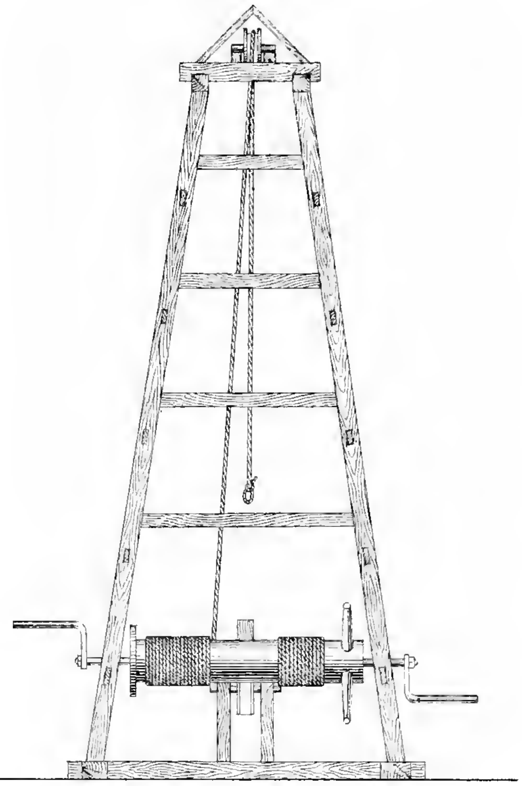

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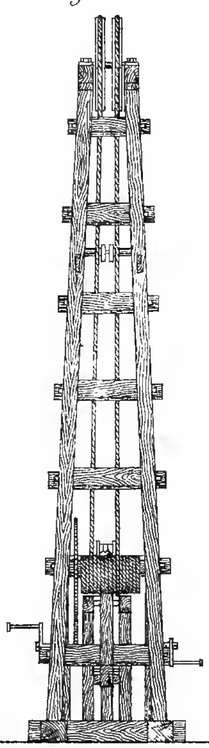

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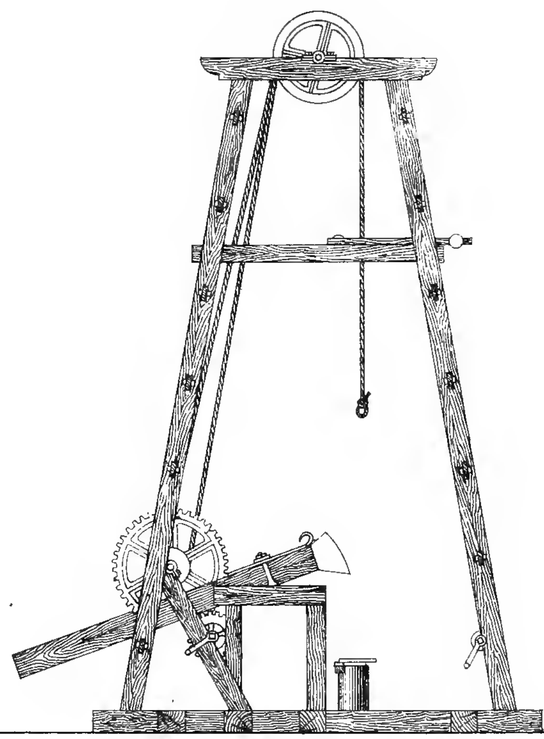

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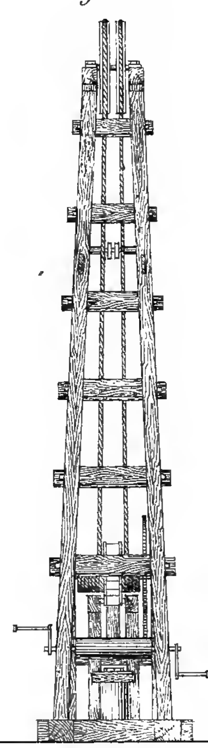

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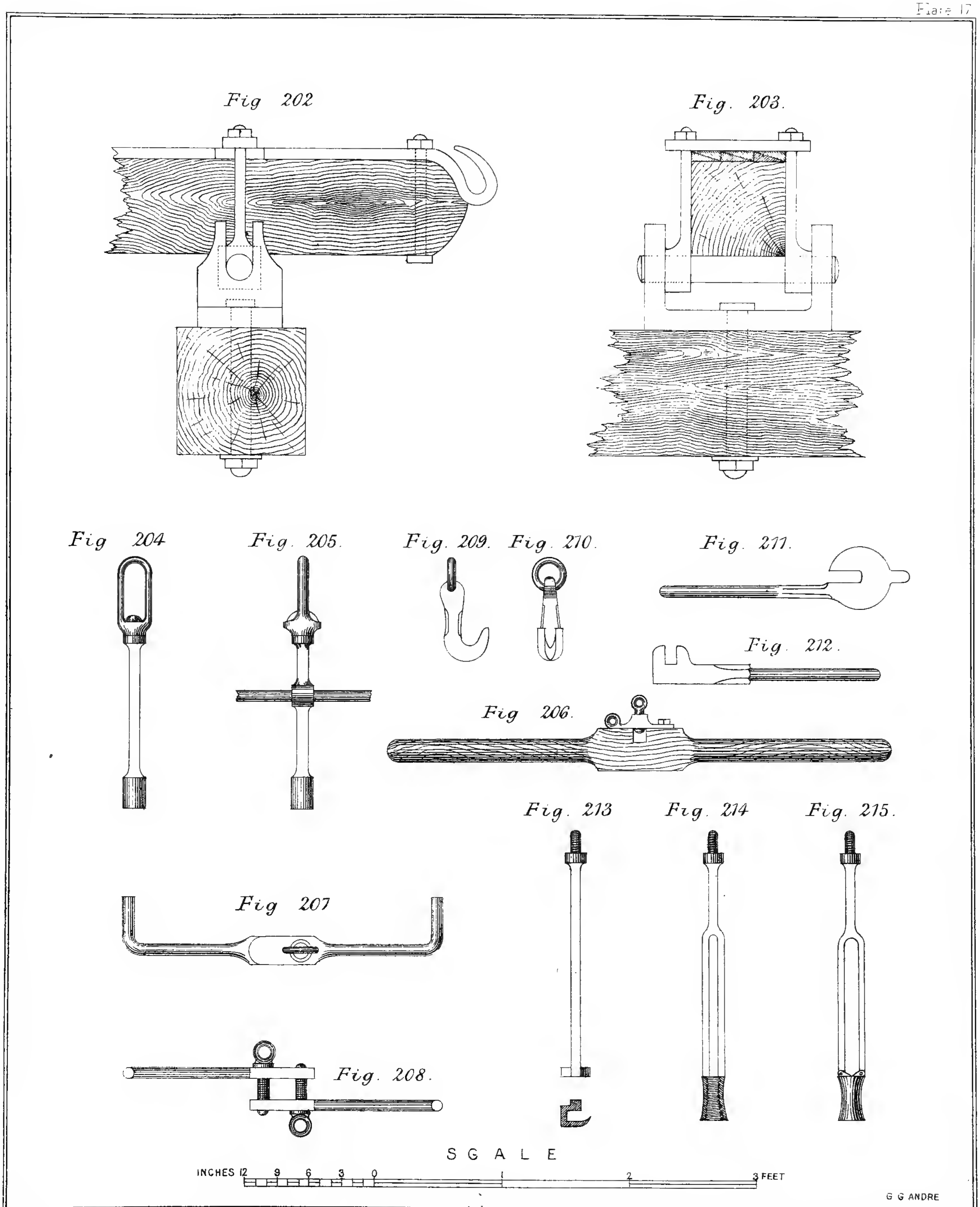

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Fig. 216.

Fig. 218

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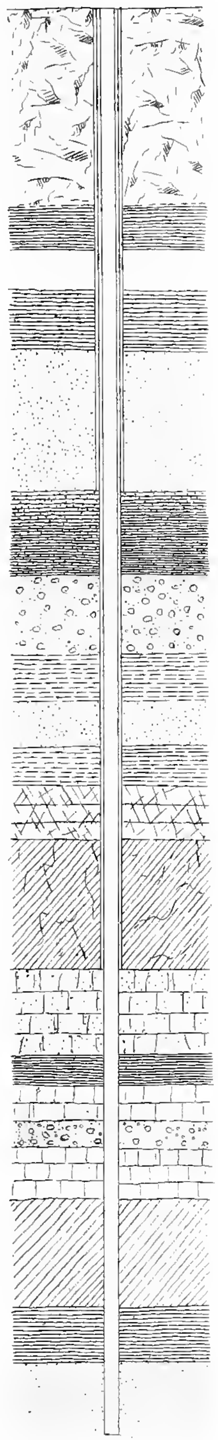

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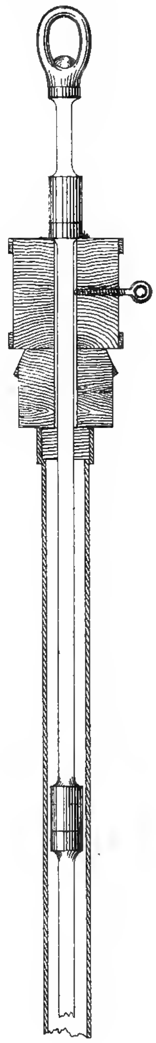

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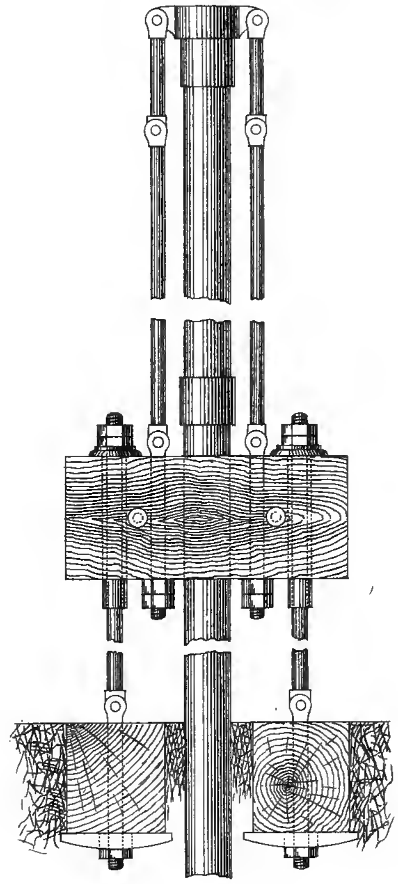

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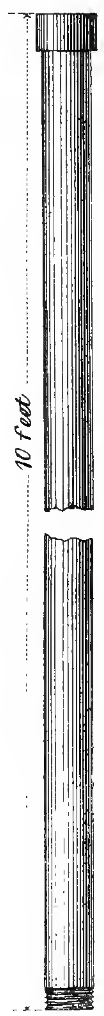

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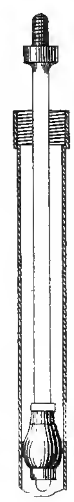

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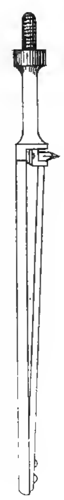

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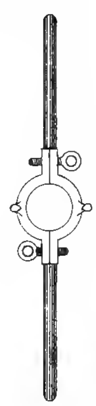

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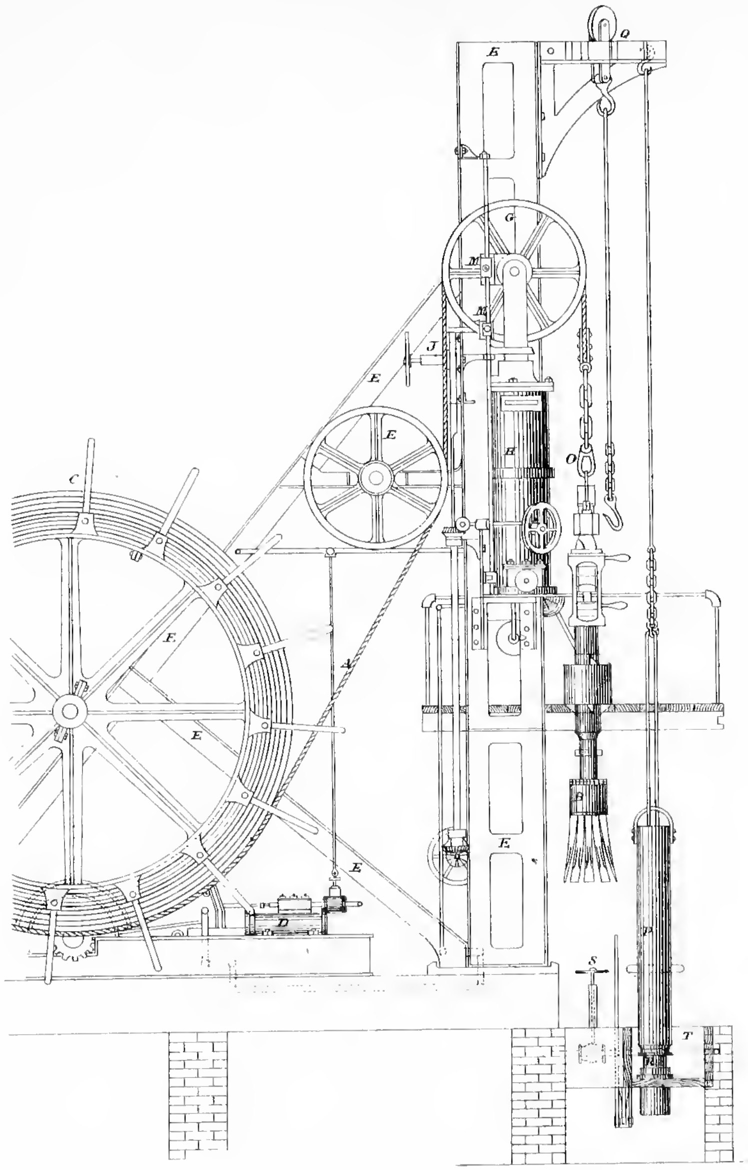
Fig 224



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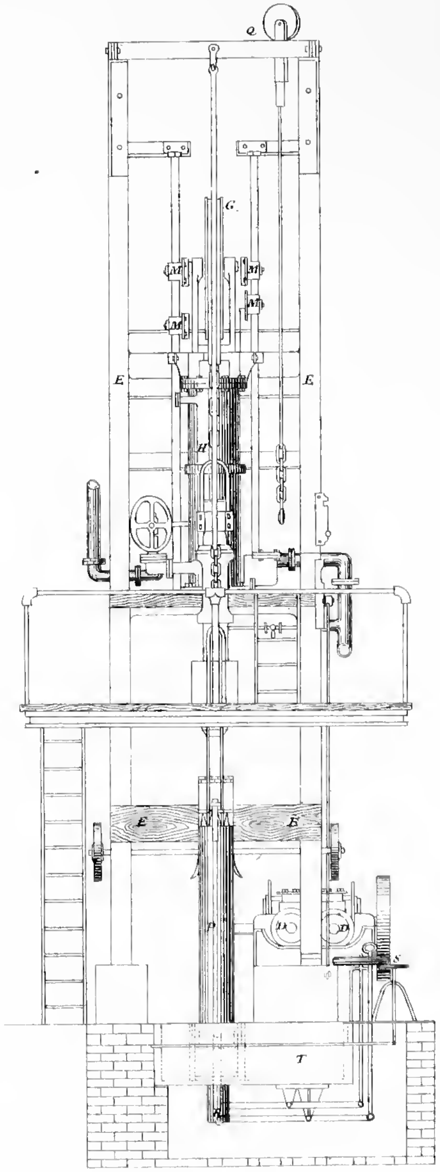

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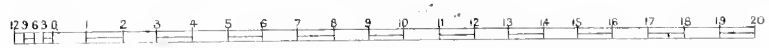

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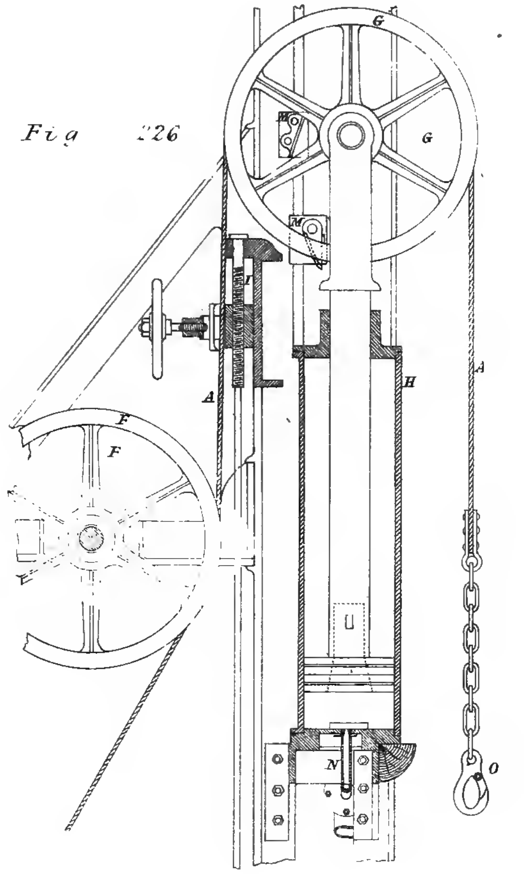
Fig 226



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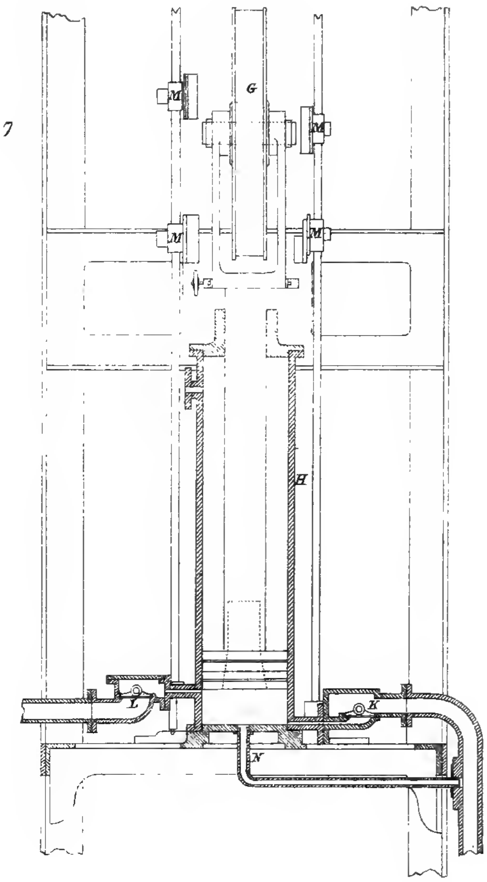

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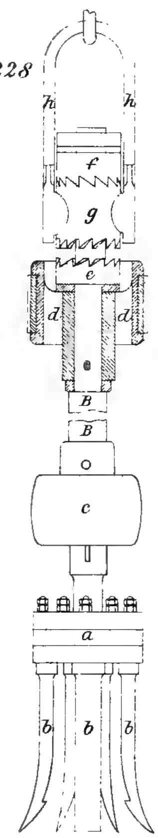

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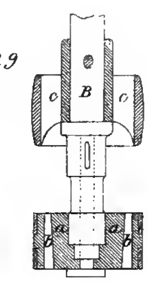

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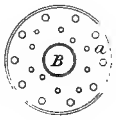

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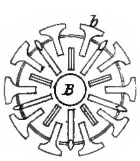

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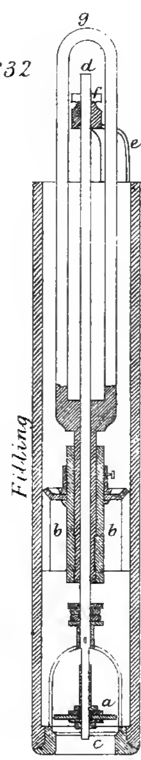

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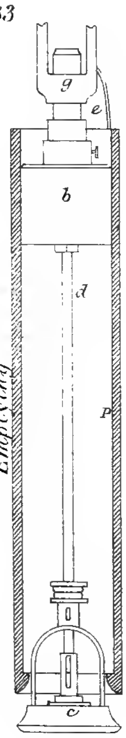

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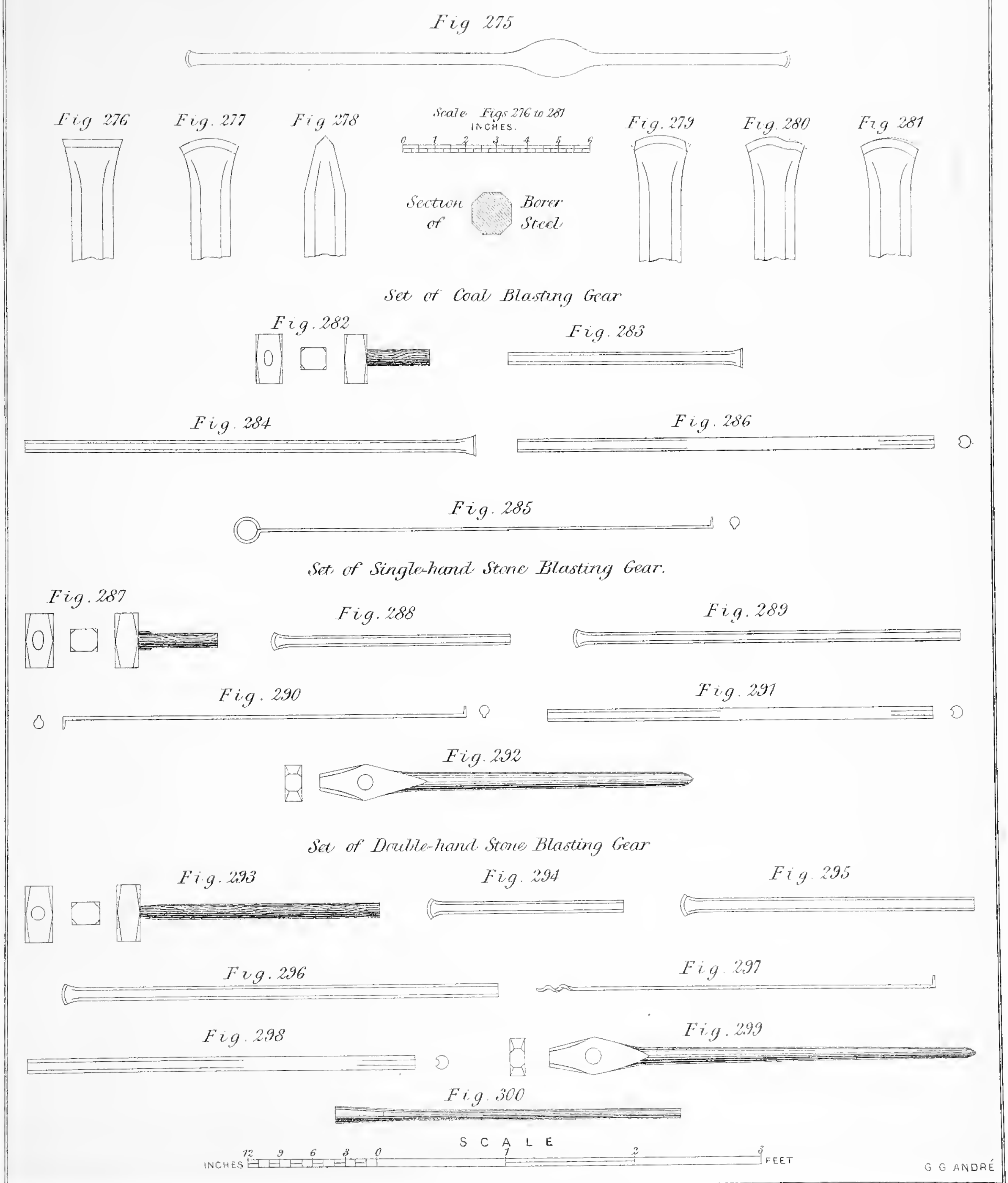

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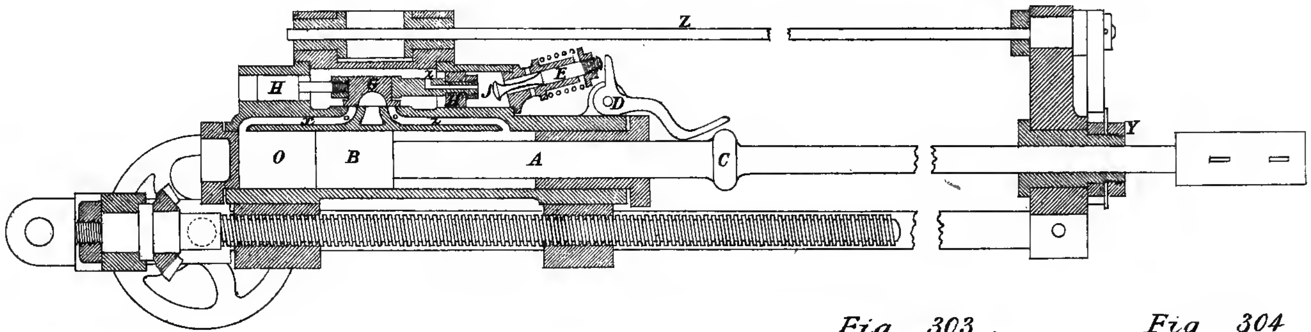
DUBOIS-FRANÇOIS.

Fig 301.



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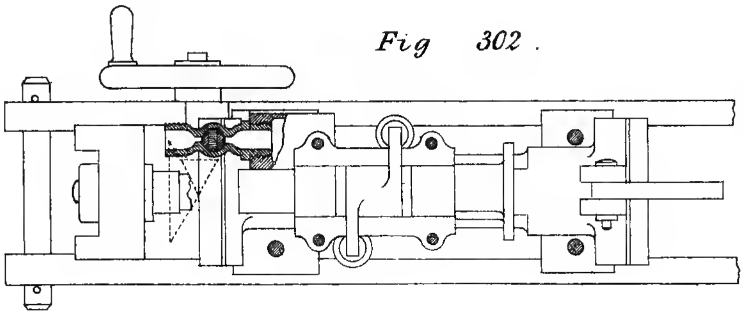

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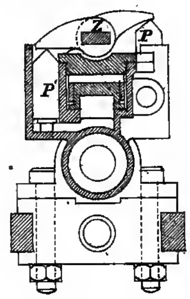

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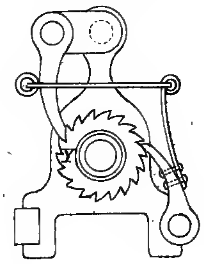

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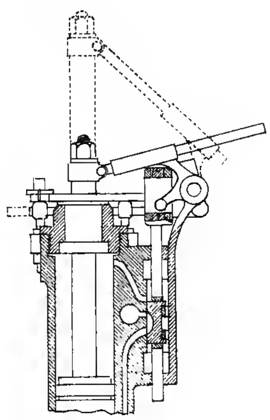

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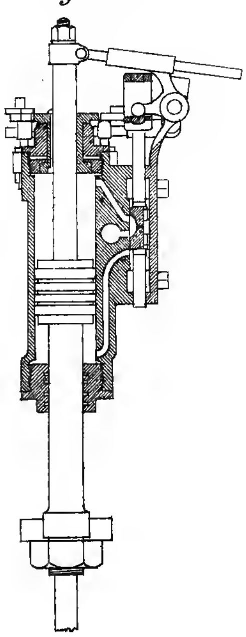

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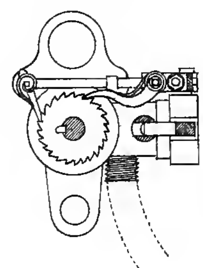

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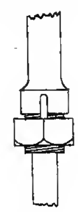

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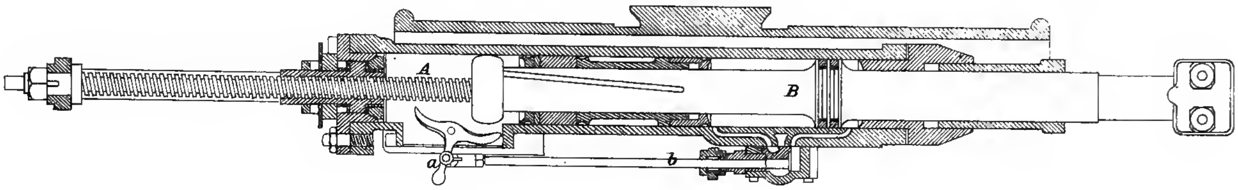
BURLEIGH

Fig. 309



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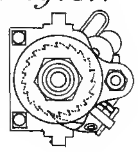

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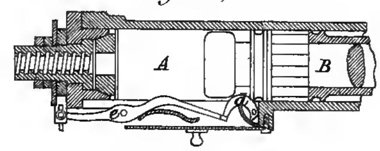

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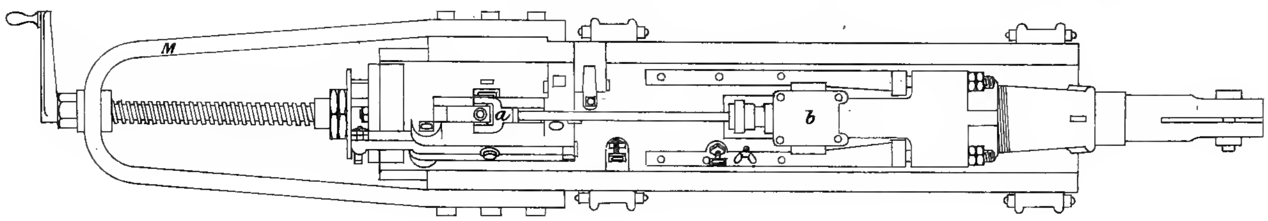
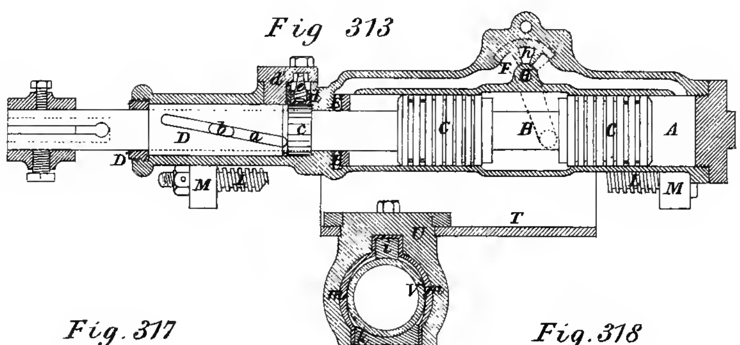


KAINOTOMON

Fig. 313



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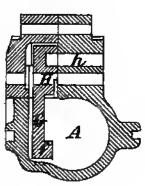

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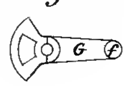

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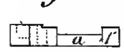

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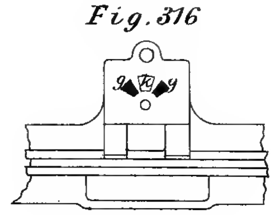

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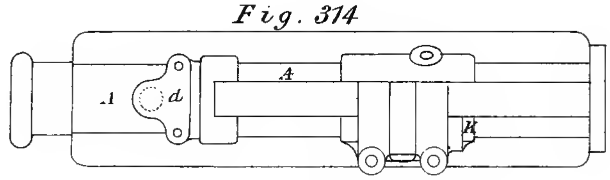

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MAC KEAN.

Fig 315

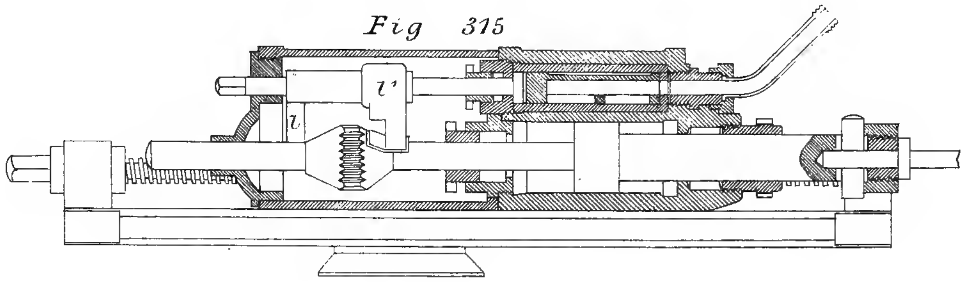


Fig 316

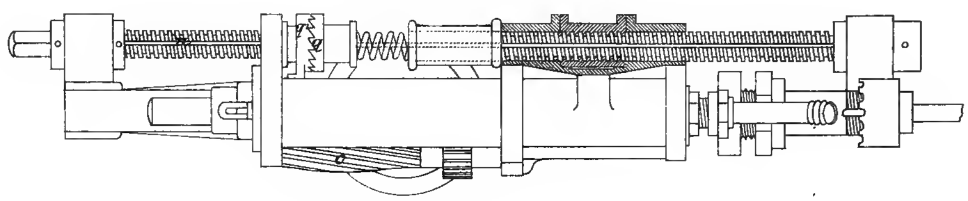


Fig 318

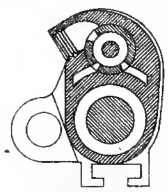
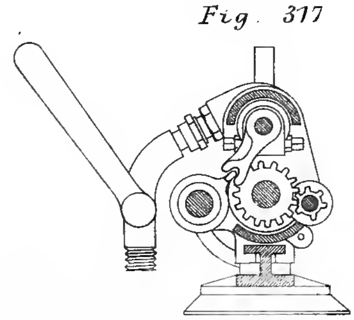


Fig. 317



INGERSOLL

Fig 319

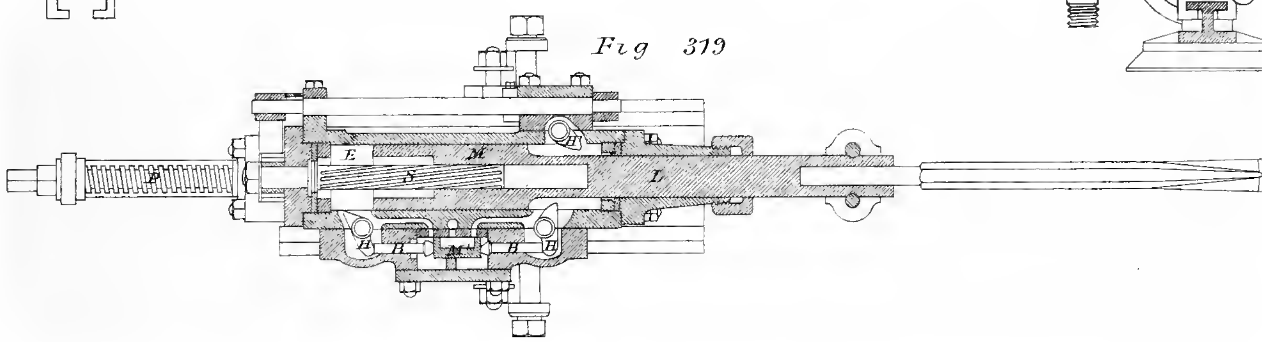


Fig 320

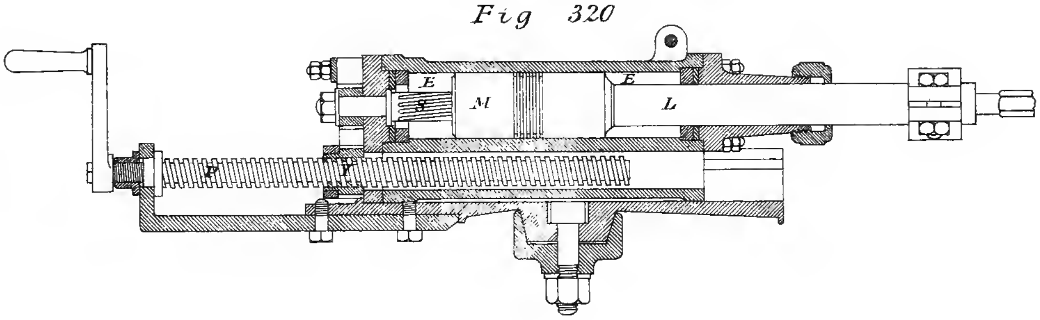
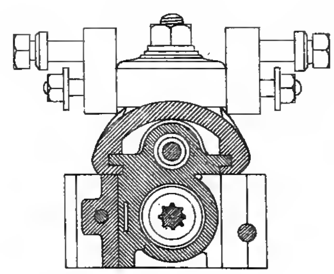


Fig. 321



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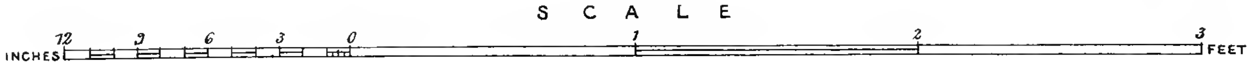

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Fig 324

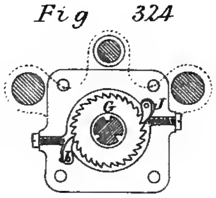


Fig 322

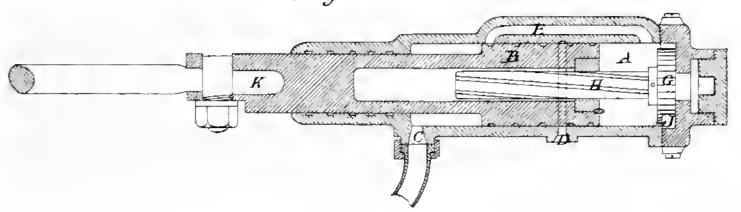
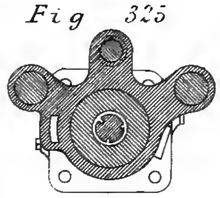


Fig 325



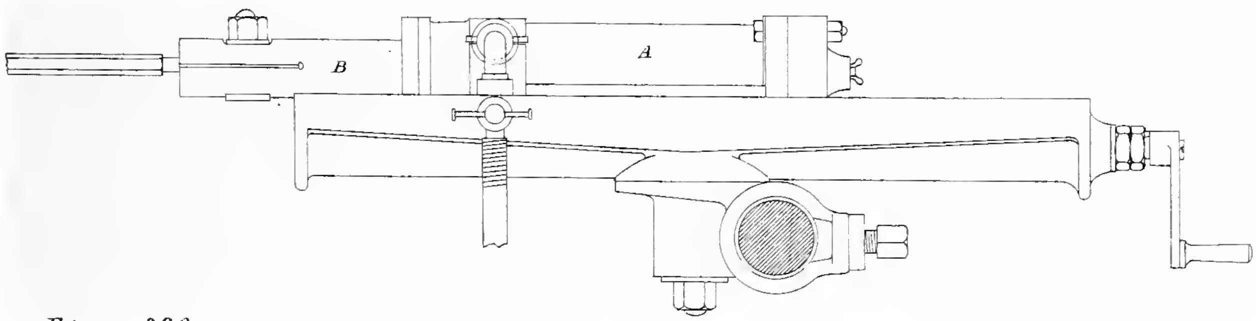
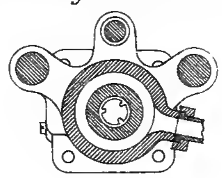


Fig 326



WARSOP.

Fig 327

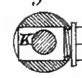


Fig 328

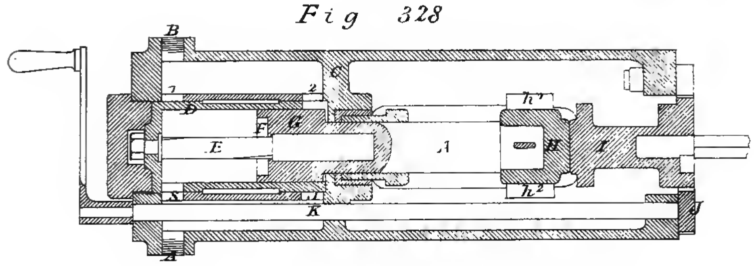
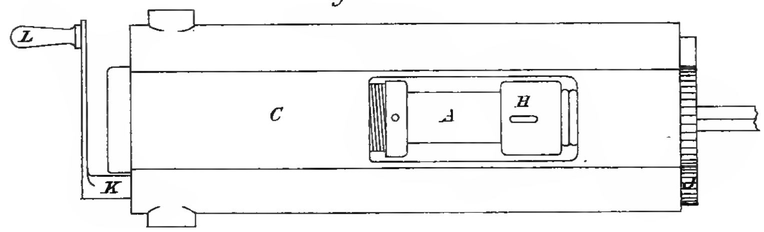


Fig 329



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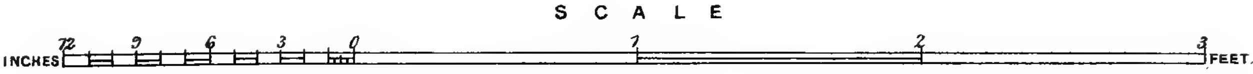

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ESSOR AT THE SARREBRUCK COLLIERIES.

Fig 332

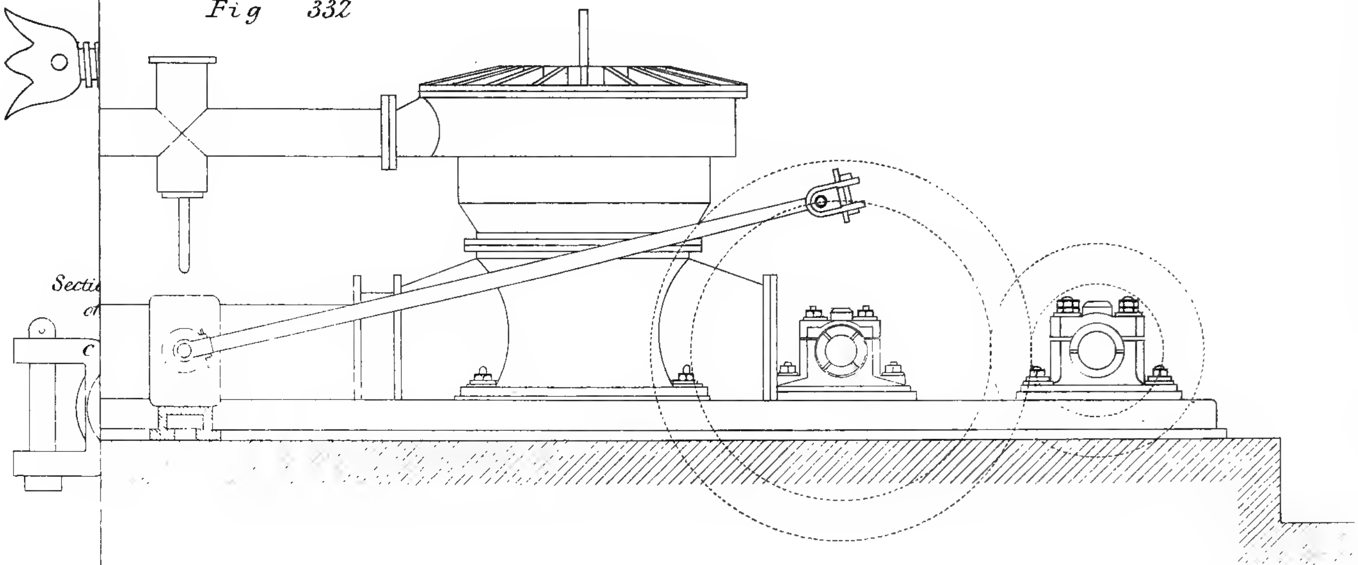
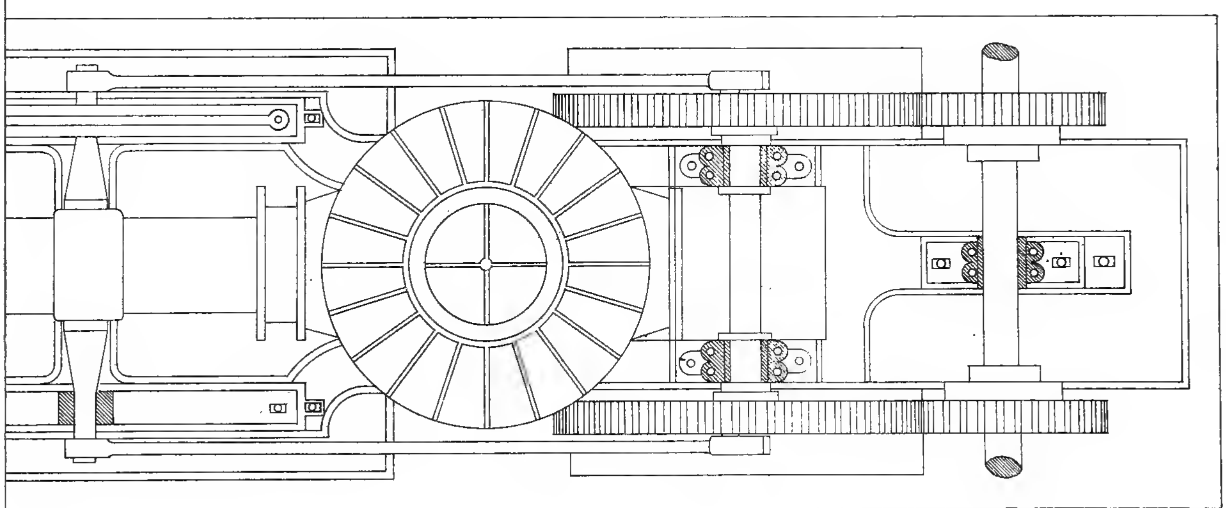


Fig 333.



2 FEET

15 16 17 18 19 FEET

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AIR – COMPRESSOR AT THE BLANZY COLLIERIES

Fig 342

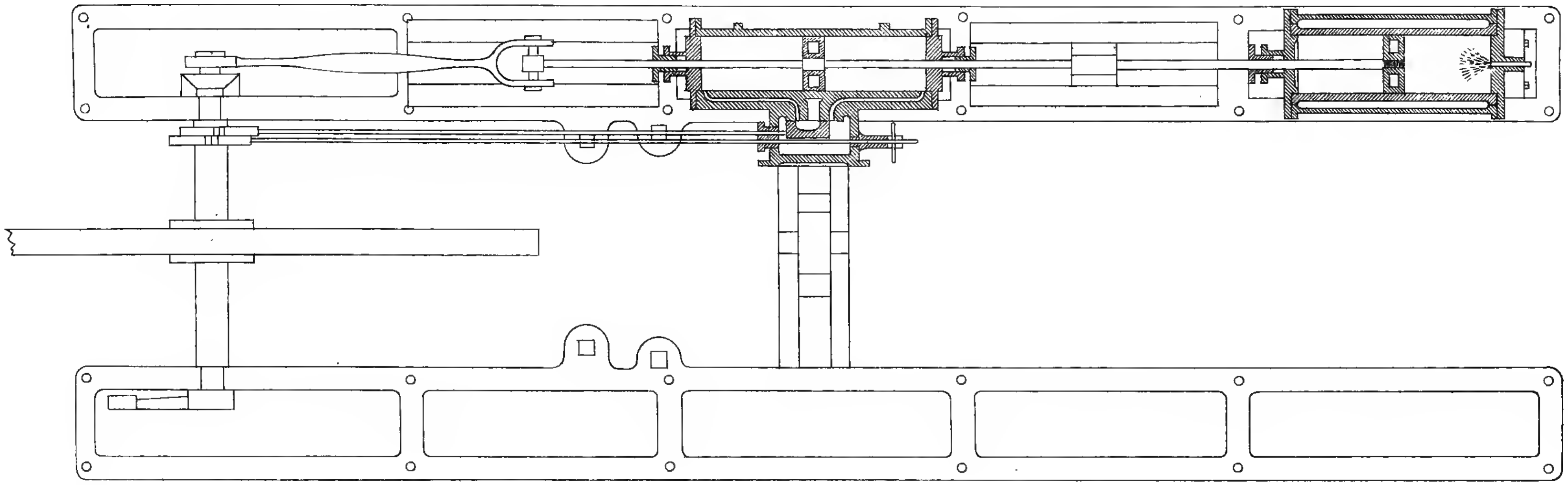


Fig 244

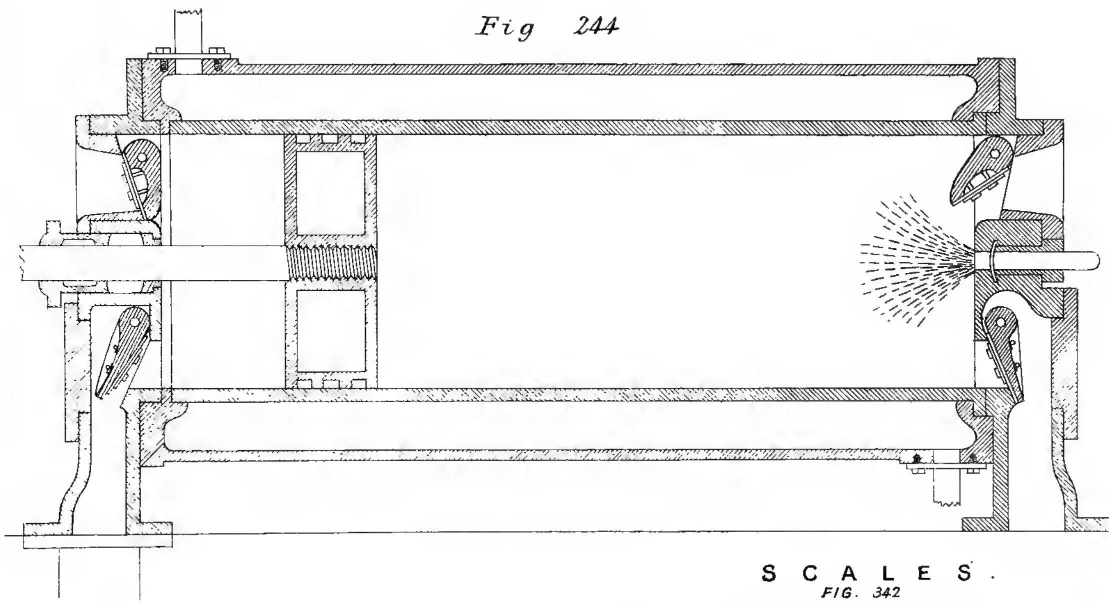
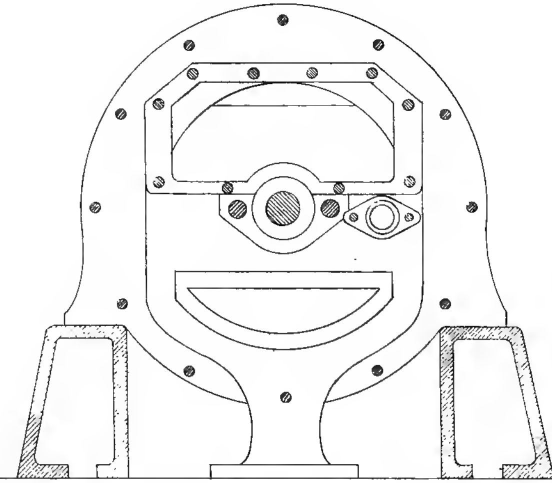


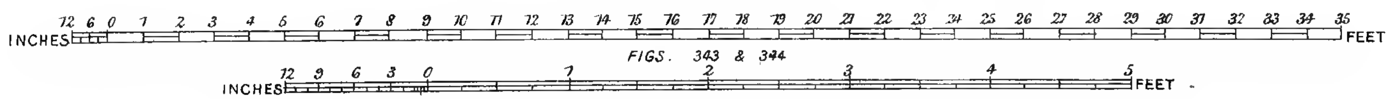
Fig. 343



SCALES.

FIG. 342

FIGS. 343 & 344



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BORNHARDT'S ELECTRICAL MACHINE

Fig 368.

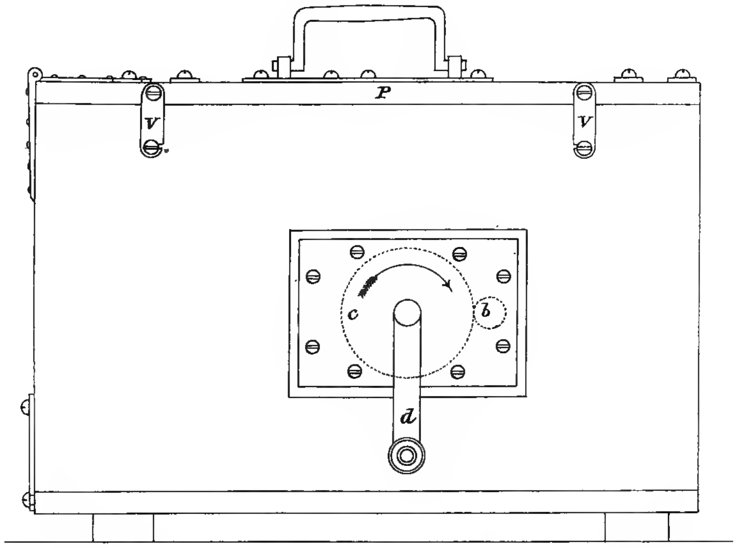


Fig 369.

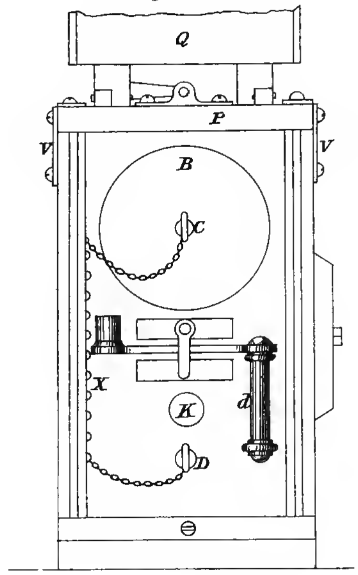


Fig 370.

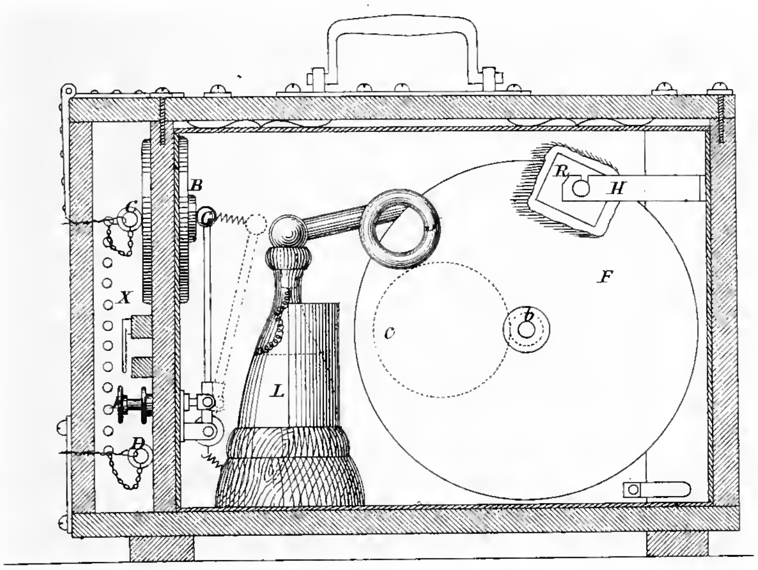
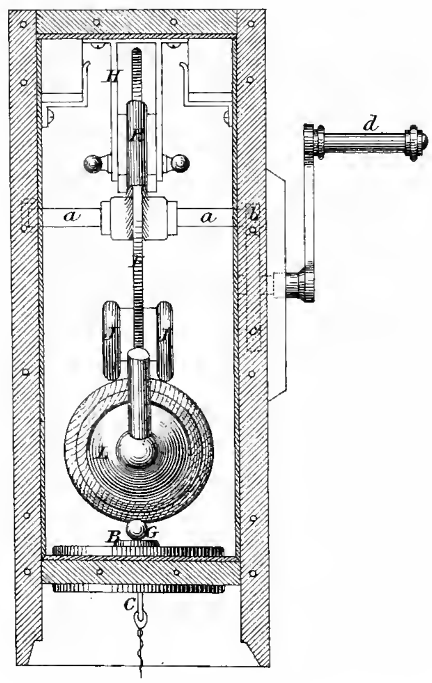


Fig 371.



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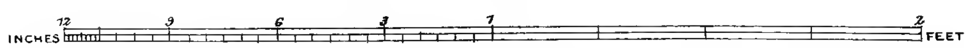

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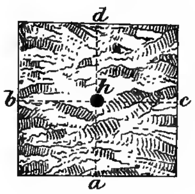
Fig. 372.



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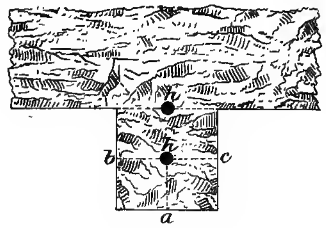

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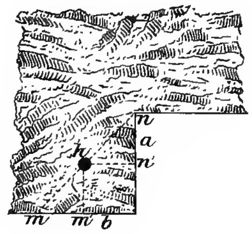

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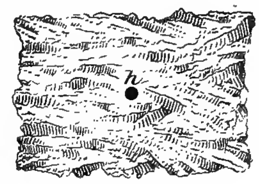

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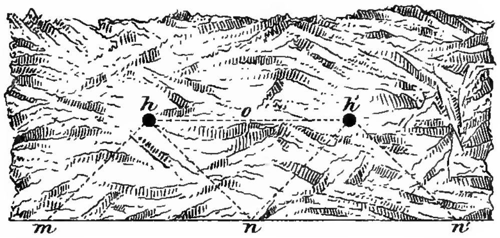

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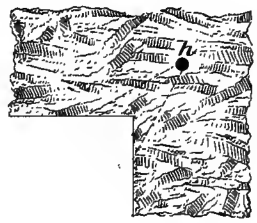

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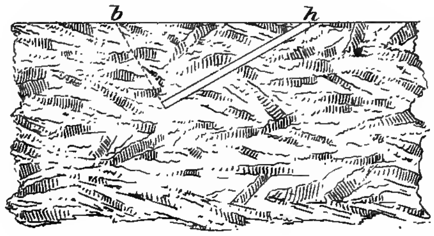

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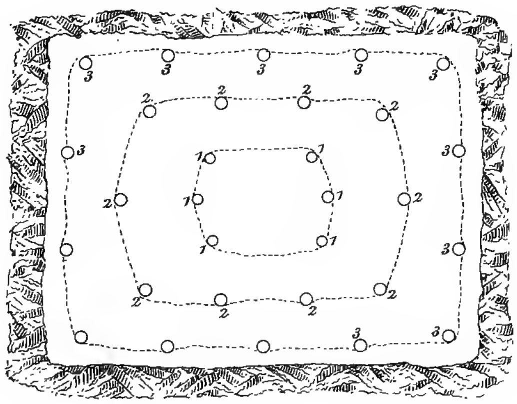

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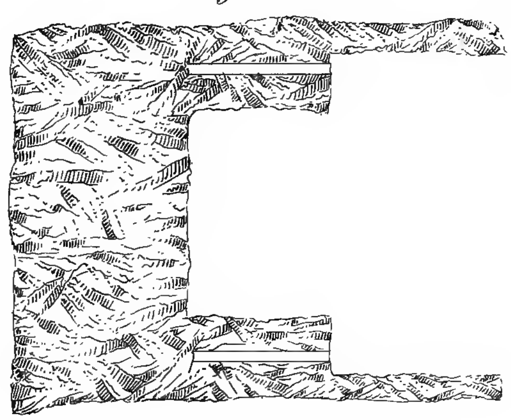

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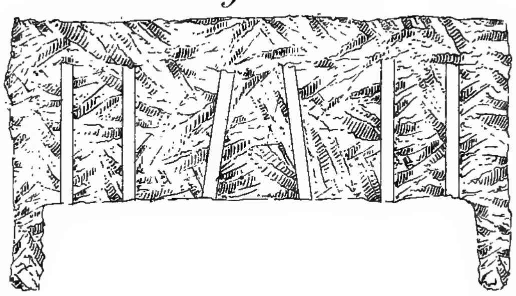

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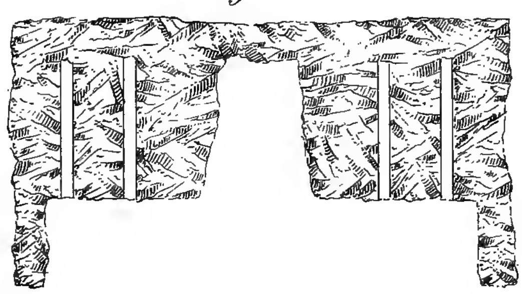

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Fig. 383.

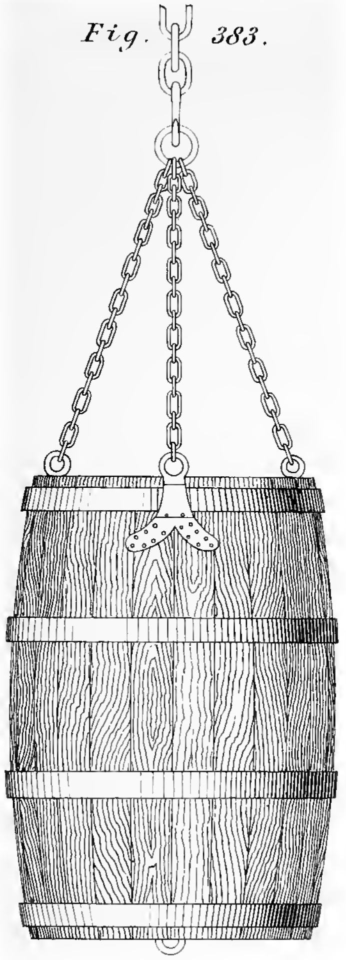


Fig. 384.

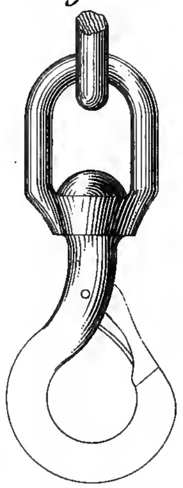


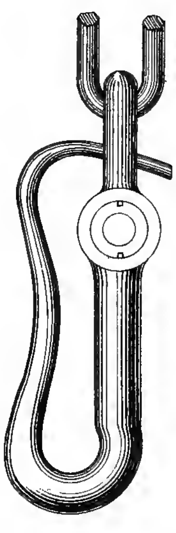
Fig. 386.

Fig. 387

Fig. 388.

Fig. 389

Fig. 385.



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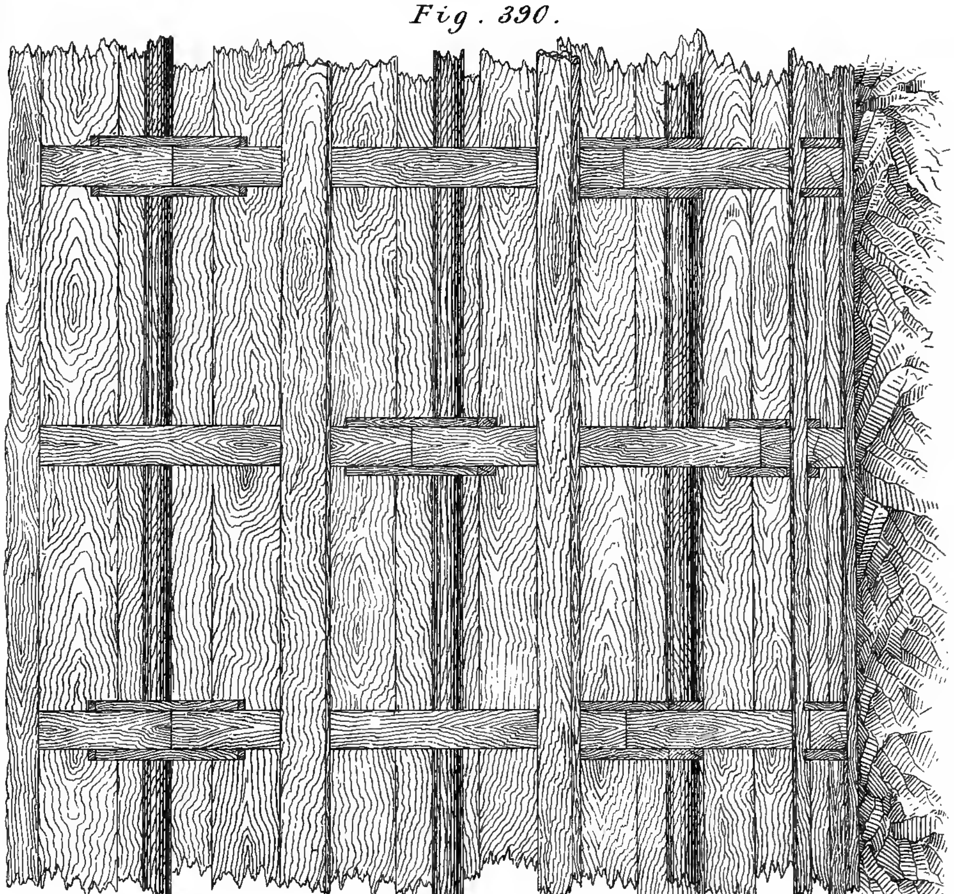

SCALES.

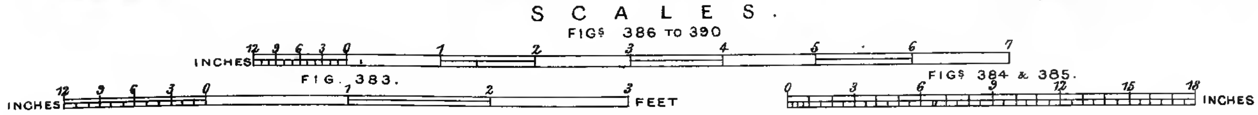

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Fig. 391.

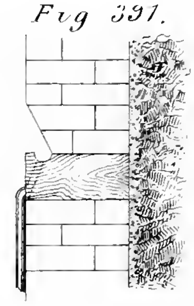


Fig. 392.

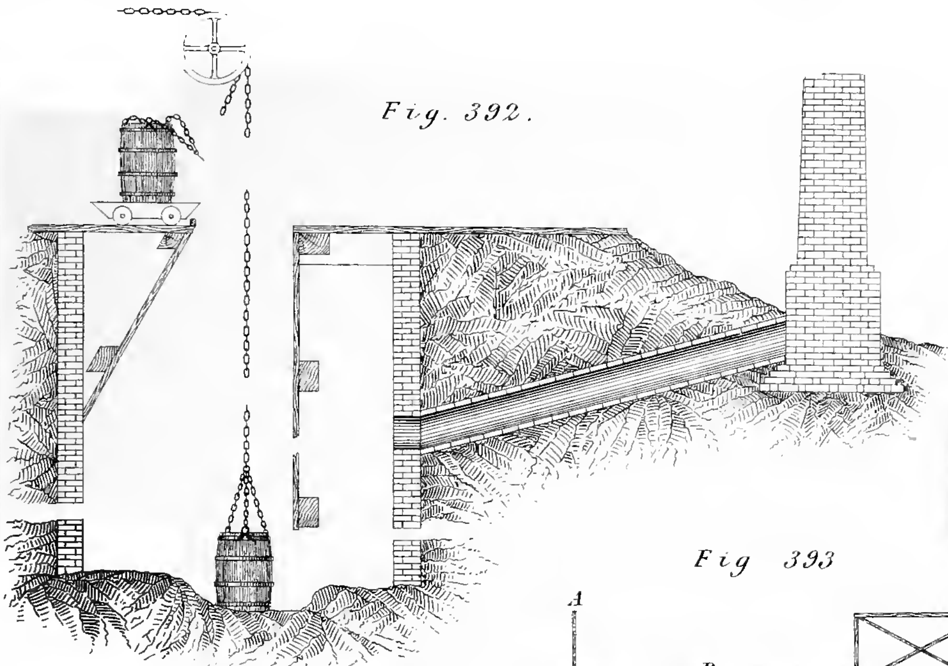


Fig 393

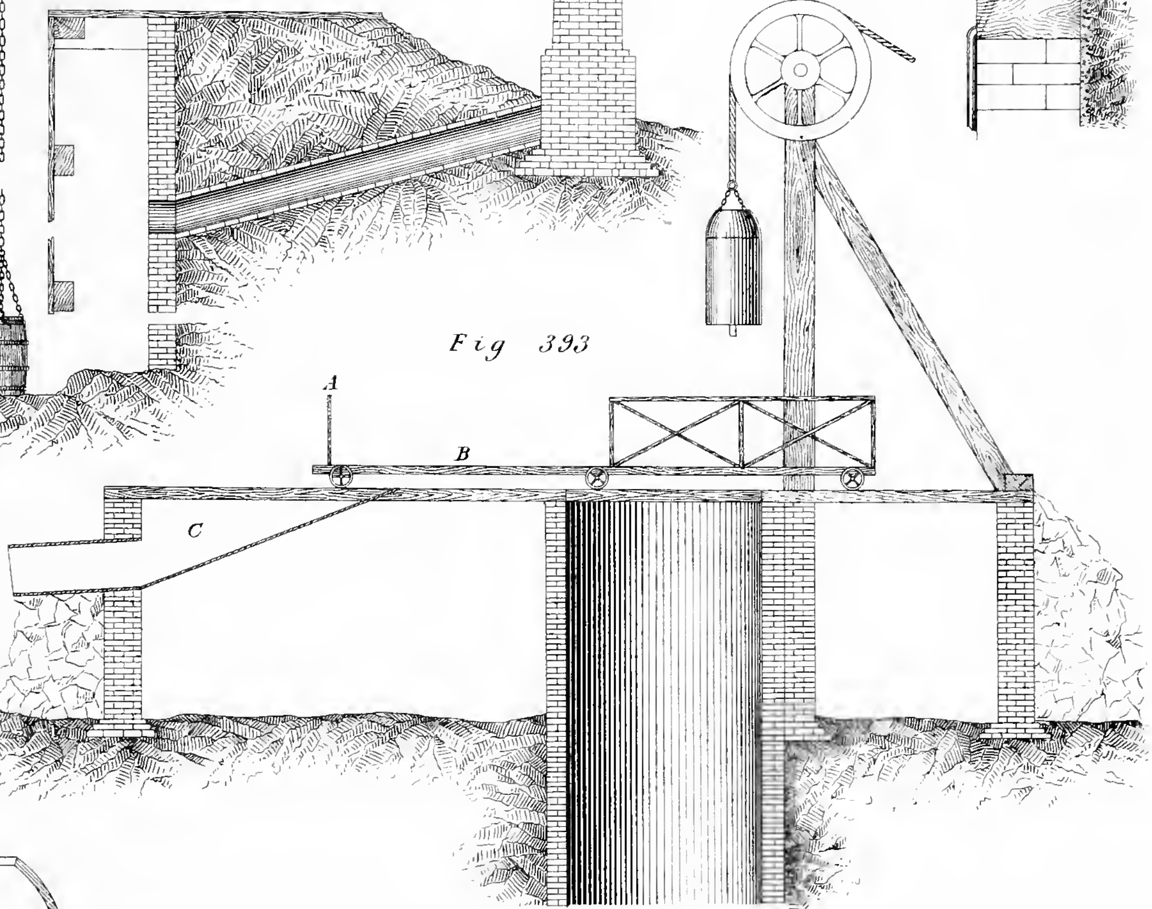


Fig. 395.

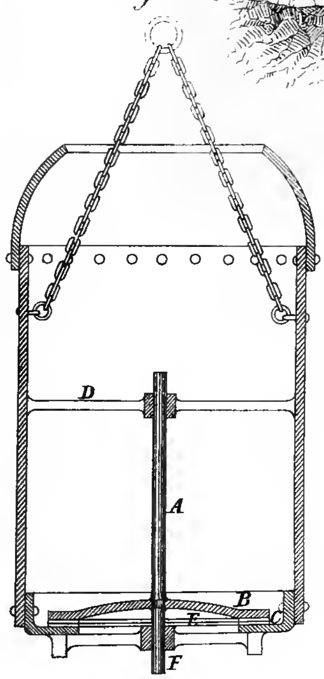
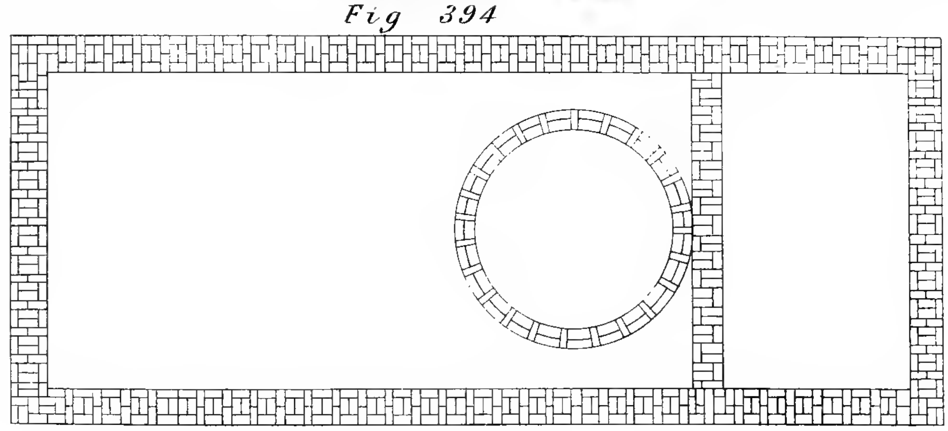


Fig 394



S C A L E S

FIGS 392 TO 394.

INCHES 12 6 0 1 2 3 4 5 10 15 20 25 30 36 FEET.

FIGS 391 & 395

INCHES 12 9 6 3 0 1 2 3 4 5 FEET.

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Fig. 397.

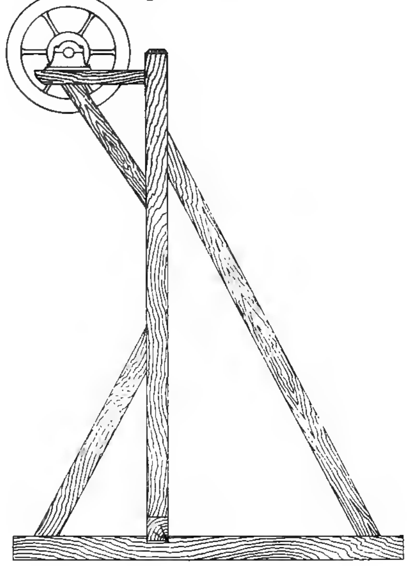
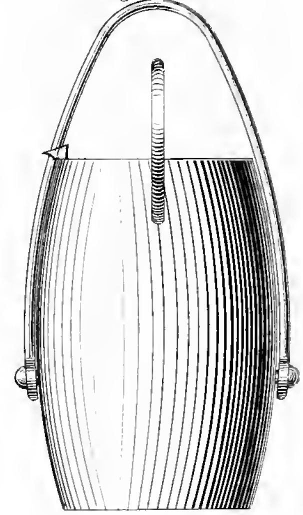


Fig. 399.



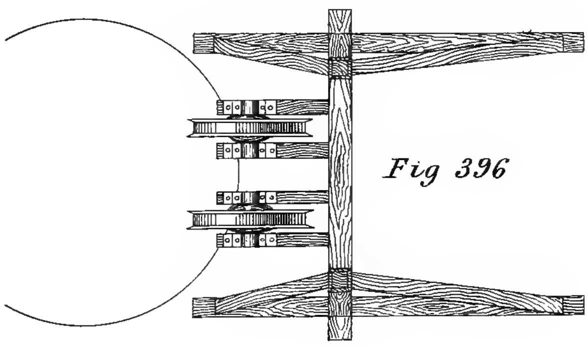
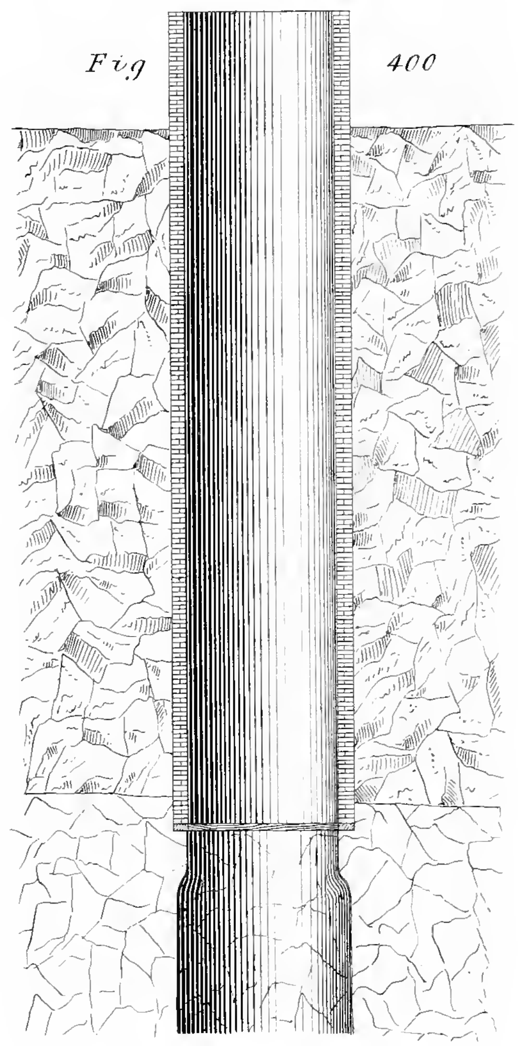


Fig 396

Fig 400



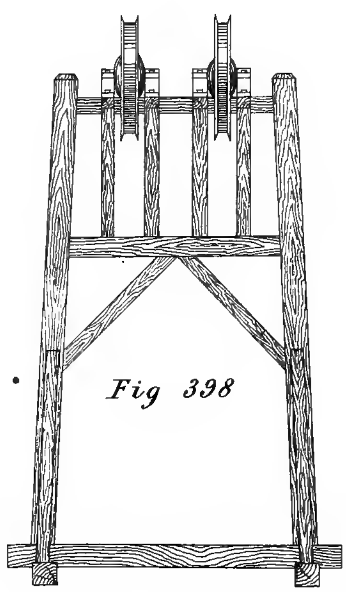


Fig 398

SCALES.

FIGS 396 TO 396

INCHES 12 6 0 1 2 3 4 5 10 15 20 23 FEET

FIG 339

INCHES 12 3 6 3 0 1 2 3 FEET

FIG 400

0 1 2 3 4 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 FEET

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